The Unified Learning Model

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The Unified Learning Model

How Motivational, Cognitive, and Neurobiological Sciences Inform Best Teaching Practices

Springer

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Preface

This is a book about how humans learn. Our focus is on classroom learning although the principles are, as the name of this book indicates, universal. We are concerned with learning from pre-school to post-graduate. We are concerned with most business, industrial and military training. We do not address how infants learn how to speak or walk, or how grown-ups improve their tennis swing. We do address all learning described by the word "thought", as well as anything we might try to teach, or instruct in formal educational settings.

In education, the words *theory* and *model* imply conjecture. In science, these same words imply something that is a testable explanation of phenomena able to predict outcomes of experiments. This book presents a model of learning that the authors offer in the sense of scientists rather than educators. Conjecture implies that information is incomplete, and so it surely is with human learning. On the other hand, we assert that more than enough is known to sustain a "scientific" model of learning.

This book is not a review of the literature. Instead, it is a *synthesis*. Scholars and many teachers likely have heard much if not most or even all of the information we use to develop the unified learning model. What you have not read before is a model putting the information together in just this way; this is the *first* one.

We do indeed pick and choose from the available knowledge to create this synthesis. What we do not do is overlook certain facts or data, or shape the data to fit our model. To the best of our knowledge, we are able to account for *all* of the known *data* about learning.

We do not necessarily account for anecdotal information. For example, there are many legends regarding autistic savants. If savants really do spontaneously show skills in the absence of learning activities, then our model is wrong. There are abundant anecdotal reports of such savant skills. When studied closely, however, savants appear to learn in the same way as other humans. Autistic savants seem to be flawed in not being able to learn as broadly as most of us can. We speculate that these savants become narrowly skilled not because of special gifts but only because those narrow skills are the ones that they can most easily attain.

Why did we write a book? Our goal is to reach those entrusted to guide the learning of other people. Teachers are an understandably skeptical audience. If the truth be told, teachers have been trained in so many ideas (fads) that controvert their experience that they don't really believe much that is labeled with the term theory. This model has something very important going for it, however. It explains and predicts how learners in classrooms actually do behave and learn. Teachers will see that right away. What's very important is that, in a very critical and fundamental manner, the model informs us about ways we can try to help our students learn better.

It's one thing to tell a story that classroom teachers can believe; it's quite another to tell one that scholars and researchers of teaching and learning will find acceptable. That left us with a serious challenge; could we create one book that addressed both groups? We decided that, rather than write two books or a series of papers, we would write a book in which the chapters had extensive, detailed notes and comments. The notes are aimed at researchers, and include citations and arguments used to justify what appears in the text.

This book has six authors. Duane Shell is an educational cognitive psychologist. His knowledge provided the background from which most of the rest of the model was developed. David Brooks is a chemist who once studied the mechanisms of enzyme action. That work involves figuring out the details of atoms and molecules that one never sees; he is trained in developing models about how things that he can't see actually work. It was Brooks' insight accounting for motivation that opened to path to the unified learning model. Guy Trainin and Kathy Wilson both are educational psychologists who prepare classroom teachers and study strategies for effective teaching. They checked the entire manuscript to ensure that no claims about classroom teaching were made that did not enjoy research support. Doug Kauffman is an educational psychologist who studies how feedback and motivation impact students' academic engagement and achievement. Lynne Herr is both an instructional technology consultant and a technical writer. She worked to make a book in which very complex technical content is co-mingled with more ordinary content understandable to those well-trained teachers for whom cognitive science is new.

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Chapter 1
The Unified Learning Model

The Unified Learning Model (ULM) is a model of how people learn and a resulting model of teaching and instruction. The academic literature is filled with models about learning, teaching and instruction. The most obvious question then is, "Why do we need another theory/model of learning?" Our answer is that the current literature contains only limited theories about isolated specific learning and instructional phenomena. As a result each of these theories explains some, but not all learning phenomena. In addition, each tends to have its own vocabulary. The result is a hodge-podge of specific learning principles and teaching guidelines that often seem in conflict with each other.

The ULM, as its name suggests, is a unifying synthesis of these existing theories. The ULM is not based on some revolutionary new research findings on how people learn. In fact, while recent advances in neurobiology and brain science have enlightened our understanding of the underlying neural mechanisms involved, we have known how people learn for a long time. There are very mature and well researched areas within the broad field of learning and teaching. What the ULM does is bring these disparate topic areas together under a single umbrella. It connects them together with simplicity and clarifies the ways in which they are interconnected.

The ULM accomplishes this by focusing on the basic processes and components of learning. Our contention in this book is that the components of the ULM underlie all learning phenomena. Hence, all current models and theories of learning, teaching, and instruction can be subsumed within the ULM. Our goal with the ULM is to replace the current diverse and confusing array of learning concepts and terminology with a scientifically grounded concise set of core learning principles. If you understand these ULM principles, you understand how learning occurs and how this learning can be facilitated by teaching and instruction.

Following what is commonly referred to as Occam's Razor (or the rule of parsimony), we aim to suggest a model that is simple while explaining all observed phenomena.[1] So what are the components that underlie all learning phenomena? In the ULM there are three: working memory, knowledge, and motivation.

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Working Memory

The centerpiece of the ULM is working memory. Working memory is where temporary storage and processing of information happen in the brain. Suppose someone were to read to you a series of single digit numbers at a rate of one per second (for example, “one, three, seven, four . . .”). You then are expected to recite back those same digits. Most of us can recall around seven digits without error. With just a little practice, we can do much better – say 15–20 digits. The number of digits is a crude measure of your working memory capacity, and “the place” where you do this is called your working memory. Working memory is central to all current models of cognition and neurobiology. In the scientific literature, one cannot talk about thinking, attention, decision making, brain functioning, or, most importantly, learning without talking about working memory. Understanding working memory is the key to understanding learning. So you may ask, “If working memory is so important, why have I never heard much about it?” “Why isn’t working memory the primary topic in every pre-service or in-service education course?” We have asked these questions ourselves. Our answer is this book.

The way working memory functions dictates how learning happens and what instructional methods and techniques facilitate or hinder learning. A science of learning, teaching, and instruction must be based to a great degree on the science of working memory. The ULM is this working-memory-based science of learning. We will spend considerable time discussing how working memory operates, how working memory produces learning, and how the operation of working memory can be influenced through teaching.

Knowledge

The ULM, however, includes more than working memory. The second core component of the ULM is knowledge. In the scientific literature of cognitive psychology, cognitive science and neuroscience, knowledge means something very different than the way educators typically think of the term. Educators usually think of facts and general concepts when they hear “knowledge.” For example, think of the first level of the original Bloom’s Taxonomy, the “knowledge” level. A revision of the original taxonomy calls this the “remember” level.[2] In the scientific literature, however, knowledge means *everything* that we know. It not only means facts and concepts, but also problem solving skills, motor behaviors, and thinking processes. Every category of Bloom’s Taxonomy, then, is knowledge to a cognitivist. Knowledge is kept (or stored) in long-term memory. Psychologists generally just call this *memory* and drop the “long-term” modifier. Memory is the cognitive term for the brain and nervous system, thus knowledge is everything we know or can do that is stored in our memory.

Knowledge has a two-fold role in the ULM. First, knowledge is the goal of the ULM. The purpose of learning is to increase the many facets of our knowledge.

Learning has occurred when our store of knowledge is increased or changed. In one very important sense, knowledge is the outcome or result of the operation of working memory. It is working memory's product. Knowledge, however, has a second function. Knowledge influences how working memory operates. The things working memory can do are affected by existing knowledge. In relation to learning, you may have heard of this as "the prior knowledge effect": the more you know about something, the easier it is to learn something new about it. So knowledge is a process of working memory as well as its product. We will devote much time to discussing how knowledge is increased, how it becomes more sophisticated, how it moves through Bloom's hierarchical taxonomy, and how this increasing knowledge impacts future learning.

Motivation

The third and final component of the ULM is motivation. Educators are immediately aware of how important student motivation is in the classroom. Motivation is discussed often in education. It is framed in terms of things like interest and preference or building students' self-confidence and self-esteem or rewards or goals. Motivational ideas and constructs are seemingly everywhere, and motivation is currently one of the most highly researched topics in education.

The ULM has a very specific role for motivation. Motivation is the impetus for directing working memory to a task; in our case, directing working memory to the task of learning. To our knowledge, the ULM is the only model of learning or motivation that explicitly links motivation to working memory.[3] Motivation is an inherent component of working memory operation and plays a critical role in effective and efficient allocation of working memory to learning. Understanding how motivation works in conjunction with working memory will help teachers understand how the various motivational constructs they have heard about actually work to motivate students to learn. So we will spend much time examining how motivation and working memory operate.

Three Principles of Learning

The ULM is founded on three basic principles of learning:

1. Learning is a product of working memory allocation.
2. Working memory's capacity for allocation is affected by prior knowledge.
3. Working memory allocation is directed by motivation.

These three principles of learning form the foundation for a complete theory of instruction and teaching. Simply put, teaching that follows these principles will be effective; teaching that does not follow these principles will be ineffective.

The remainder of this book is divided into two sections. The first will cover the three basic components of the ULM to explain how working memory, knowledge, and motivation work to produce learning. This is the underlying model of learning that forms the foundation of the ULM and from which the three basic principles are derived. The second will use the three basic principles of learning to develop recommendations for successful teaching and instruction.

Notes

1. http://en.wikipedia.org/wiki/Occam%27s_razor (Accessed March 22, 2009).
2. The original taxonomy is found at: Bloom, B. S. (1956). *Taxonomy of educational objectives: The classification of educational goals*. New York: D. McKay. The revised taxonomy is found at: Anderson, L., & Krathwohl, D. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom′s taxonomy of educational objectives*. Columbus: Merrill. The original levels were labeled knowledge, comprehension, application, analysis, synthesis, and evaluation. The labels in the revised taxonomy are remember, understand, apply, analyze, evaluate, and create.
3. Hayes offered a framework that included motivation and working memory together as part of a scheme for understanding writing. The ULM is a general learning model that applies to all learning (not just how to write) and makes specific the role of motivation in the learning process. Hayes, J. (2000). A new framework for understanding cognition and affect in writing. In R. Indrisano & S. J. Squire (Eds.), *Perspectives on writing: Research, theory, and practice* (pp. 6–44). Newark, DE: International Reading Association.

Part I
Developing the Unified Learning Model

Chapter 2
Learning

> *Understanding how neurons work together to generate thoughts and behavior remains one of the most difficult open problems in all of biology, largely because scientists generally cannot see whole neural circuits in action.*
>
> Meisenböck[1]

What is learning? A seemingly simple question, but the answer is both simple and complex. At its most basic, learning is a relatively permanent change in a neuron. Over the past half-century, scientists have uncovered most of the basic biological and chemical processes involved in learning at the neural level. Learning results when the synaptic potential of a neuron, the likelihood of a neuron transmitting an electric potential, is systematically changed.[2]

As you might expect, the biological and chemical processes involved in this change are extremely complex. Luckily, in the same way that an engineer building a bridge doesn't need to deal with the subatomic structure of the atoms that make up the materials she is building with, educators do not need to deal with the underlying biochemistry of the neuron to develop effective teaching and instruction. The ULM, however, derives its principles of learning from the neurobiology of learning. So this is where we start.

The Neurobiology of Learning

The brain and nervous system exist in large part to take in information from the world and use that information to direct motor action in the world. Although the brain and peripheral nerves do perform other basic and often automatic functions such as control of physical, hormonal, and body regulatory functions, like heart beat, we are concerned with those parts of the brain and nervous system involved in higher learning and behavior, that is, the parts that matter for school learning.

These parts of the brain are situated primarily in the cortex. Once we move beyond the brain areas involved in basic biological functioning, the vast majority of the remainder of the brain is devoted to gathering sensory inputs and generating motor actions. The brain has two primary jobs. One is to take in and save information about the world from the senses (hearing, taste, touch, smell, vision, and

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internal feedback from those internal sensors that sense how things are "working together" called proprioceptive feedback).[3] The other is to produce motor outputs that generate functional behaviors in the world like finding food, building shelter, and speaking. Most of the higher brain areas of the cortex are devoted to sensory input areas (the occipital lobe for vision; the olfactory cortex for smell, etc.) and motor control areas (including one-to-one mapping of physical areas of the body like fingers on the motor cortex itself). The remainder of the cortex is devoted to specialized functioning like language or is available as a general memory area.

Much of early infancy is devoted to the development of sensory and motor areas for things like learning to interpret visual input and learning basic motor skills like crawling and walking. The developmental biologist and psychologist Jean Piaget extensively studied this period of what he called the *sensory motor* stage of development. Most of the learning in this period is driven by biological maturation of neural and body areas, and involves gaining understanding of what sensory input means in relation to objects and other people in the outside world, as well as gaining control of coordinated motor behavior. During this period there is extensive development of fine motor control in the cerebellum. There is also extensive development of specialized cognitive processing areas like Broca's and Wernicke's areas for speech and language processing.

While learning and development in infancy is a fascinating field of study, we will not consider it in any depth. The processes that underlie learning in the ULM are operative at this age, but the child does not yet possess language or other symbol systems that are the currency of school learning. While the ULM accounts for all learning including early years, our intent in this book is to focus on school learning.

The Operation of the Neuron

For all of the biochemical complexity underlying how a neuron works, its operation can be described in simple terms: A neuron "fires" or produces an electrical output in response to having been "fired upon" by other neurons. All neurons have an input end and an output end. The input end can be connected to (receive input from) one or many other neurons. Once this input passes a threshold, the neuron sends an electrical potential that produces release of biochemicals (neurotransmitters) at the output end that are input to the neurons with which it is connected. These connections are called *synapses*.

It is this basic operation of the neuron that defines what it means to "learn." *Learning occurs when the firing ability of a neuron is changed.* This can occur within the neuron by changing the firing threshold or by increasing the amount of input being received. Again, the actual underlying biochemical processes involved in neural learning are very complex, but these neural processes are driven by very simple mechanisms.

Stated simply, neurons are changed by activity. The internal mechanisms of the neuron are changed each time the neuron fires. The more the neuron fires, the easier it is to fire again. Similarly, the connections between neurons are changed with each firing. When neurons that are connected together fire together (simultaneously or in sequence), the connections are strengthened.

At birth, the brain contains massive numbers of neurons and neural connections. As noted previously, the majority of these are specialized neurons that record sensory input and direct motor movement. Regardless of what role an individual neuron plays, however, all follow the same learning mechanism. If it is fired, its ability to fire again is increased; if it is not fired, its ability to fire again is decreased. As the brain matures or “develops”, the pattern of neurons and how they are connected is determined by what neurons and neuronal connections fire or don’t fire. Neurons grow or die and neuronal connections are created or eliminated based on which are active.

One of the best examples of this is spoken language. Among all languages combined, there are approximately 800 phonemes (meaningful vocal sounds) used. At birth, humans can vocalize all of these phonemes. Any specific language (like English or French) only uses a subset of these phonemes (in English it is approximately 44 depending on dialect). As a child learns her native language, the neural connections that produce the phonemes in that language are strengthened and those not in the language are weakened. Over time, the ability to produce phonemes that are not part of the native language is diminished or even lost. This in part accounts for the difficulty that persons learning a second language in adolescence or adulthood can have with accurate pronunciations and why their speech often has a pronounced accent. Although phoneme neurons can regrow or restrengthen as the second language is learned, they may never fully recover to the level of a native speaker, which is why an adult language learner may never be able to speak without an accent no matter how strong their language fluency.

The Architecture of the Brain

The human brain has an identifiable anatomy. Areas of the brain are in the same location in all people. Most of these areas contain neural groups that perform certain functions. For example, the occipital lobe toward the back of the skull processes visual sensory input from the eyes. Although the gross anatomy of the brain is a result of genetics, the actual neural connections themselves mostly result from learning – that is neurons firing or not firing. So while it may be accurate to say that vision or language are processed in specific regions of the brain, how a region processes information is determined by how the neurons in that region have been strengthened or weakened through past firing. This notion explains why brain surgeons often map the functional brain regions during surgery and especially prior to removing tissue[4]; we’re all the same, but we’re all different, too. Our brains show a remarkable plasticity. In the event that a procedure ends up with tissue being lost, it remains possible for other tissue to acquire the lost knowledge through subsequent patterns of neural firing using an area of the brain that is not generally associated with that function.[5]

In response to the “nature vs. nurture” argument of whether the brain (or behavior) is primarily due to genetics or biology or due to experience, *we can safely say that it is both*. While the brain does come prewired to receive input from the world in certain ways (the cones and rods in the eyes respond only to certain parts of the light that is in the world and the occipital lobe processes these in specific ways) or produce a defined set of motor movements (the human arm and leg can only move in certain ways but not in others in response to neural signals), the actual things that we see (what we come to recognize as objects or meaningful visual entities) or movements we can do (such as dance or catch a ball) are the result of our experience which has produced specific patterns of neural firing.[6]

It is proper to say that the macro architecture of the brain is genetic, but the micro-architecture is environmental. Because the macro architecture is common to all people, it also is proper to say that differences between people are due to differences in micro-architecture. One person doesn’t differ from another because she somehow has a unique anatomical structure that someone else doesn’t have. For the most part, one person differs from another because she has a different pattern of neurons and neural connections within each of her brain areas. The vast majority of these differences in patterns are due to learning.

What Is Knowledge?

Knowledge, as we use the term in the ULM, is entirely the result of the micro-architecture of the brain. While it may be possible to locate the processing of something like numbers and mathematics to a rather specific anatomical region of the brain, the ability that one has to do computation, algebra, calculus or other mathematics is not a result of having or not having this anatomical region; everyone has this region. It is due to neural patterns in that region having been strengthened and weakened in ways that correspond to learning algebra, calculus, etc. The strengthening and weakening of neurons is learning. *Thus, the micro-architecture of the brain and as a result, virtually all of our knowledge is the result of learning*.

It also happens that brain tissues can acquire new micro-architectures as the need arises. For example, amputation of an extremity can lead to “reassignment” of the brain tissue that once took care of input/output from the amputated extremity to another task.[7]

How Learning Works

We have stated that learning is the change in a neuron that strengthens or weakens its ability to fire. But, how does this neuronal change happen? We have broadly noted that it happens because the neuron fires, but what exactly determines when a neuron fires?

Each of our sensory and internal homeostatic regulatory systems has a dedicated input area (the occipital lobe for vision for example). These input areas have some dedicated neural storage areas and the neurons in these are fired, and hence strengthened or not strengthened, based on the direct pattern of input from the sensory organ to which they are connected. These mechanisms account for gross sensory recognition and discrimination processes and require no further neural systems. While these neurons are following the same neural learning mechanisms, we are not really concerned with this basic level of processing in the ULM.

We are concerned with the next levels. We receive a tremendous amount of sensory (and internal proprioceptive) input at any one moment. The knowledge present in a sensory input area is extremely low level. It is something like boundary discriminations between light and dark areas that define the presence of an object in the visual field. There is no knowledge of what this object might be in the sensory area. Sensory areas simply aggregate their specific component pieces into an output that is sent out of the sensory area to the rest of the brain.

The place where this sensory output is sent is working memory. Working memory does not have a clearly defined anatomical area. It appears to be a collection of brain regions in the prefrontal cortex along with other structures such as the hippocampus. Each of the sensory (and proprioceptive) input areas generates neural output that is sent as input to working memory. There is too much of this sensory input to deal with at the same time, so a primary function of working memory is to choose what of this input will be ignored and what will be processed. The general term for this is *attention*. *Working memory is where, at a given moment in time, we attend to some inputs and not others*.

Sensory input that is attended to in working memory is a candidate for being stored in the long-term permanent memory neurons of the brain. Most of these areas are in the cortex and are collectively referred to as long-term memory or just memory. Although the full transfer process in the brain is not well understood, input that is attended to activates neurons in a temporary memory area, possibly the hippocampus as well as some others, that create a neural representation of the sensory input in working memory. This information is maintained over a few hours interval through what is known as *long-term potentiation*, a process that keeps the temporary neural pattern active so that it doesn't disappear. In other words, long-term potentiation is a state of storage in between permanent or long-term storage and fleeting or momentary storage. If the neural pattern does not decay, it activates a neural pattern in the cortical region that produces a permanent memory trace of the original input. *As this trace learning occurs in the cortical neurons, their patterns of connectivity become changed.*[8] Psychologists use the term *storage* to describe the process of turning a specific input into a permanent trace.

Meaningful Learning

It is reasonable to ask at this point, "so what?" Yes, a "trace" of the sensory input has been laid down in the cortex, but what good is this? An isolated memory of a single sensory image, say a round object, isn't really very useful. How is this "knowledge?" We will grant that if all working memory did was to create random isolated, stored sensory inputs (images, sounds, smells, etc.), it wouldn't be worth much. But, working memory does much more.

Suppose that the sensory input attended to in working memory was something you had attended to before. In this case, there would already be a neural pattern in the cortex that was the same as this input. When this happens, the neural pattern in the cortex is fired or activated. Rather than create a new memory, working memory "recognizes" the pattern as a known and the existing memory is strengthened. If a sensory input occurs frequently, the strength of the cortical neural pattern can become large and the speed at which working memory can "recognize" it (or match it to an existing pattern) gets faster. The general term for this process of matching working memory input to long-term memory neural patterns and activating them is *retrieval*. American adults usually can decide quickly that a round object is an apple as opposed to another similarly sized object like a baseball, or distinguish a Granny Smith apple from a green tomato.

Now, let's assume that rather than a single sensory input, there were two sensory inputs in working memory. When this neural pattern is stored, both sensory inputs will be part of the pattern. Now at a later time, one of these sensory inputs is attended to. This will trigger retrieval of the pattern, but it won't be just this one sensory input pattern that is activated and retrieved, it will be both of the originals. This is because both were stored together originally. Remember, neurons are chained together so that the activation of one "fires on" any other neuron it is connected to. This chained firing of the one sensory pattern match will activate the second. When you see an apple, you almost certainly also are firing up what you have stored under "sphere."

Let's next assume that one of the original sensory patterns was attended to in working memory, but there was a third new sensory pattern in working memory with it. The original sensory pattern would "retrieve" the two patterns in long-term memory that are connected and because these are now active, the new sensory pattern in working memory would be connected to them. The resulting neural pattern in long-term memory would now have all three sensory patterns and could be retrieved by the presence of any of the three.

This process can chain together sensory input and existing cortical neural patterns virtually infinitely. This is how our knowledge of things and concepts are built. The entire process runs by *pattern recognition*. We "understand" what something is because a pattern of sensory input in working memory matches a pattern of neurons in cortical long-term memory. When one part of a chain is matched, the entire chain is activated because patterns are linked by chaining of neurons. The process of match and retrieval is called *spreading activation*.[9] You see the Granny Smith apple, but you also seem to be able to link the visual input to input from smelling and tasting it.

While we often speak of bits of knowledge being "stored together," as in the case of the taste, odor, and appearance of a Granny Smith apple, it is not necessary that this storage takes place in side-by-side brain structures. They only need to be linked. It has been pointed out that "Knowledge of how distinct brain regions contribute differentially to aspects of comprehension and memory has implications