# Chapter 6
# How the ULM Fits In

At this point we believe that we have made a case for a unified learning model around the concept of working memory wherein working memory capacity, prior knowledge, and allocation account for learning. It is extremely unlikely that any of our readers have come from this perspective. The purpose of this book is to introduce this unified learning model. Most readers will have at least some, if not much, of their training rooted in notions that use different perspectives and vocabularies. So far as we know, no other model accounts for motivation in the same way as the unified learning model. The purpose of this chapter is to try to tie the notions of the ULM and its vocabulary to other concepts, ideas, and theories with which our readers are more familiar.

## Ability

Most teachers will tell you that successful learning depends upon three things: prior knowledge, ability, and motivation. What do we mean by ability? For over a decade, one notion that has pervaded the education and popular literatures is that of intelligence, a construct associated with mental ability.

While it is not our intent to review the literature on intelligence, some background is in order. Intelligence has at times been thought to be measured by a single number, the intelligence quotient (IQ).[1] Spearman was the first to identify a common factor underlying virtually all mental tests that he called the general factor or "g."[2] Generally speaking, persons with high IQs are thought to be mentally more able than those of lower IQ. This extends to the point that learning disability is commonly, and controversially, determined by measures of IQ outstripping academic achievement.[3] Quite some time back, the general factor g was separated into two distinct parts: *fluid intelligence* conceptualized as overall general mental capacity applicable to new and unfamiliar problems, and *crystallized intelligence* conceptualized as learned knowledge and skills applicable in those problems where extensive prior experience matters.[4]

As we have discussed previously, in the ULM, ability or intelligence is a function of working memory capacity and knowledge. There has been a growing consensus

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that fluid intelligence is basically working memory capacity.[5] For example, training on working memory has been found to improve scores on fluid intelligence measures.[6] In the ULM, working memory is what limits cognitive processing capability. This would be consistent with the notion of fluid intelligence as basic cognitive or mental capacity. Raw working memory capacity is approximately four slots. There certainly is individual variation in this, similar to the variation in fluid intelligence found in the general population. Memory for random numbers or letters, which is essentially a test of working memory span, is a common measure of fluid intelligence. We also see working memory as being a more fundamentally sound way to look at capacity than the older intelligence views of either g or fluid intelligence. Working memory is analyzable in more precise neurological and computational ways that go beyond the usual psychometric tests used for intelligence measurement.

The crystallized intelligence component of IQ is essentially synonymous with knowledge in the ULM. The ULM places a greater weight on knowledge (crystallized intelligence) in both ability and expert performance than is typical in most intelligence theories. As we have previously discussed, knowledge is able to actually expand functional working memory capacity. This interaction between the crystallized and fluid components of IQ is rarely discussed in the intelligence literature.

People can become highly skilled in spite of differences in raw working memory capacity or measured fluid intelligence. Given that there is important pre-selection in admittance to careers in these areas, physicians and scientists of differing ability achieve similar success in their professions. It is hard to find a nuclear physicist whom one might otherwise describe as mentally slow. Within a professional group (of physicists, physicians, electricians, etc.), fluid intelligence or raw working memory capacity matters less. Instead, within a group, what matters is knowledge. Knowledge, in turn, depends upon chunking. This has been confirmed by extensive research in expertise. Think back to our discussion of chess masters in Chapter 4. The ULM explains crystallized intelligence in terms of chunking.

When confronted with new or unusual problems or unfamiliar contexts, working memory capacity (fluid intelligence) matters more because there are no experientially developed knowledge chunks available to use. In situations where expert experience is likely, then knowledge (crystallized intelligence) – meaning available chunks – matter.

## Heredity

Whether or not to include a section on heredity led to remarkably heated discussions among the authors. The literature on heritability is connected to measures of intelligence. Notice that, in our description of the ULM so far, we used neither the word intelligence nor the label IQ. The first time we mentioned either of these has been in the preceding section. Many people have asserted that intelligence is inherited, and they use as examples the case of identical twins (monozygotic twins). The correlations of IQ between twins raised apart are high, and those between twins raised together still higher. Based upon magnetic resonance imaging studies, "brain maps" of identical twins show strong similarities; those of fraternal twins show fewer similarities.[7] Whether measured psychometrically or physiologically, genetic influences are detected when data from twins is analyzed.

On the other hand, very strong environmental influences also are measured. For example, massive IQ gains have been found for several countries over the span of one generation.[8] It is hard to see how these gains could have occurred if, indeed, IQ is under strong genetic control. In addition, many researchers have challenged studies of IQ heritability. Recent meta-analysis and reviews suggest that early studies overestimated the correlations between twins IQ and that studies of adopted children may have overestimated IQ heritability.[9] As we went to press, another study of twins appeared which, once again, probably overestimates the role of heredity.[10]

A recent review of genetics of brain structure and intelligence concludes: "Nature is not democratic. Individuals' IQs vary, but the data presented in this review and elsewhere do not lead us to conclude that our intelligence is dictated solely by genes. Instead genetic interactions with the environment suggest that enriched environments will help everyone achieve their potential, but not to equality. Our potential seems largely predetermined."[11] They previously stated: "The significant influence of heredity on IQ has been misinterpreted to imply that there is little point trying to educate or be educated, or that IQ is somehow impervious to change. This is a fallacy because many environmental factors, including family rearing environments, socioeconomic status, diet, and schooling, influence IQ. As noted elsewhere (Plomin and Kosslyn, 2001),[12] gray matter volume may be correlated with intelligence partly because more intelligent individuals seek out mentally challenging activities that increase the volume of their gray matter."

The ULM is a book about learning. As noted, brains have a macro structure largely determined at birth and a micro structure determined through learning and experience. Obviously, brain macro structure is determined genetically as well as by its in utero environment. Differences in core working memory capacity, which as we have discussed, is likely what fluid intelligence is, may be largely genetic/hereditary, may be measurable, and may emerge when truly unique situations are confronted. Any aspirational boundaries they may seem to place on a given individual, however, most often can be transcended. The data are compelling that our working memory capacity increases as our knowledge increases. Whether one is "gifted" or not, in the end it is effort that pays. Testing with an IQ of 145 in the 2nd grade will not lead to a special outcome in the absence of effort. Testing with an IQ around 90 by no means indicates that top success is out of reach.[13,14]

While we live in a society that places great weight on talent as something one is fortunate enough to be born with, at least two books view this issue quite differently. In *Developing Talent in Young People*, Bloom reports the study of over one hundred individuals thought to be at the top of their professions including mathematicians and neurologists, tennis players and swimmers, and sculptors and pianists.[15] Their status was high. For example, all swimmers were Olympians, all tennis players had ranked in the top ten in the world, and all of the neurologists had received National Institute of Health Career Development Awards. The bottom line of this study was that there were no clear early signs indicating that such levels of success would inevitably emerge. Indeed, even though they had made clear early commitments, it was by no means a sure thing that all of these persons would have been identified early as prospects for the very high attainment they ultimately achieved.

A more contemporary work by Gladwell, *Outliers: The Story of Success*, identifies opportunity and legacy as being the key factors in determining the outcomes of the most successful members of society.[13] He asserts (p. 268), "To build a better world we need to replace the patchwork of lucky breaks and arbitrary advantages that today determine success, the fortunate birth dates and the happy accidents of history, with a society that provides opportunities for all." Later he says: "Superstars are products of history and community, of opportunity and legacy. Their success is not exceptional or mysterious. It is grounded in a web of advantages and inheritances, some deserved, some not, some earned, some just plain lucky, but all critical to making them who they are. The outlier, in the end, is not an outlier at all."

One way to look at hereditary differences is that they are really small but that circumstances lead to having them multiplied. Economists often speak of multiplier effects. Educators speak of "the Matthew Effect," also described as "the rich get richer."[16] In this notion, small differences are magnified when they are encouraged, thereby attracting a potential crescendo of actions including more practice, coaching, better coaching, etc. Putting hereditary arguments aside for a moment, consider the simple developmental consequences of birth date relative to some fixed date. Athletic teams often use age to separate levels of play; no one expects 6-year-olds to compete effectively against 8-year-olds, for example. Elite Canadian hockey players are far more likely to be born during the first quarter of a year (Jan-Feb-Mar) versus the last (Oct-Nov-Dec).[17] The simplest explanation for this is that, because children playing hockey are divided on the basis of birth date with January 1 being the magic day, those born earlier are better developed (bigger, stronger) than those born later in a given year, the criterion for dividing the level of competition. As a result, they attract more praise, better coaching, more opportunities, etc. The effect (in this case likely based entirely upon birth date) is real but small, but ends up being expressed dramatically in terms of reaching elite status. Changing the date to July 1 and waiting 25 years to determine the outcome could test this hypothesis. This is highly unlikely; the apparent face validity of the argument is so strong that it is unlikely to be tested. The parallel argument for heredity would be that a small genetic difference could be multiplied. One could make a similar argument for status. That is, a three-year-old for whom coaching lessons are purchased is more likely to attain elite performance than a three-year-old without such opportunity.

When will differences in core capacity matter most? When you know nothing, then having more slots to deal with whatever is available probably is very helpful. At the other end, when you know everything – when you are a well-studied expert who knows as much as the other best experts in the same way they do – then having more core capacity also may help. In between is where most of us are most of the time. That is, we are still acquiring knowledge, likely through deliberate practice, and automating that knowledge.[18]

Of the six ULM authors, one is obese and three are overweight. We all four would like to blame our genes. However, for each of us, decrease in calorie consumption and/or increase in exercise leads to weight loss. Darn!

## Cognitive Development and Stages

Human development is obvious. It is especially obvious to those who have children or grandchildren. It is more obvious to elementary school teachers than college teachers. Clearly, there is biological maturation. Children grow physically, and this physical growth includes the brain and nervous system. There is evidence that working memory capacity increases during childhood and doesn't reach its full mature capacity of four slots until adolescence.[19]

From a descriptive standpoint, it is clear that children's knowledge and thinking also develop. In this area of cognitive development, Jean Piaget was among the first to note that children's thinking was qualitatively different from that of adults. Children don't just know less; they reason differently and perceive the world differently. Piaget was the first to systematically study this development of thinking and formulate what is probably the most widely and well known theory of cognitive development.

In the ULM, thinking and behavior are functions of knowledge in long-term memory. Changes in knowledge account for changes in thinking. Knowledge is gained through the learning mechanisms we have previously discussed. In the ULM, these learning mechanisms are properties of neurons in the nervous system. As such they cannot be separated from the biology of that system or the maturation of the underlying biology. As we noted in Chapter 2, and in our discussion of heredity in this chapter, the ULM views the macro structure of the brain as determined through genetics and the micro structure of the brain as determined through learning and experience. As such, the ULM would reject strong nativist and modular developmental theories of cognitive abilities that espouse strong gene driven development with little experiential input.[20] But, as discussed later in this chapter, the ULM is compatible with "weak" modular theories such as Geary's primary and secondary categories of learning.[21] The ULM also would be compatible with theories that see development of working memory capacity as a major contributor to cognitive development.[22] The work of Kandel on the neurology of learning from which we have drawn most of our neural learning mechanisms has begun focusing on how gene expression within the neuron interacts with environmental stimuli to produce the neural learning we have described previously.[23]

Teachers are probably most familiar with Piaget's theory. Piaget called knowledge structures schemes or schema, a terminology which has become standard in contemporary learning and cognitive theories for describing large integrated networks of knowledge. We have also adopted his terminology in this book to describe large declarative knowledge networks. Piaget viewed schemes as interacting with the world through assimilation and accommodation. He saw these as kept in balance by a process of what he called equilibration. The equilibration process responded to situations where existing schemes were inadequate in some way, either by not being able to recognize or classify something (e.g., assimilate it as an instance of X) or not being able to adapt itself to some situation (e.g., accommodate to the specifics of the environment). Equilibration operated to compensate for these disturbances or disequilibrium by changing the knowledge structure. Compensation was accomplished in part by what Piaget called "reflecting abstraction" or the ability to separate general knowledge from its particular content. In the ULM, this would be similar to the neural processes that strip out non-repeating situated aspects of a concept leaving the general properties. These Piagetian processes have also been applied to understanding concept formation and change, especially in science education.[24]

Piaget was a scientist and viewed knowledge growth and change as an interaction between the person/child as an active, self-regulating biological entity and the world in which the person was engaged. The ULM and other contemporary learning theories see learning in most respects in the same way that Piaget viewed "development." Some contemporary theories of concept learning have even incorporated Piagetian-like mechanisms.[25] Virtually all contemporary learning theories, including the ULM, view learning as an active, self-regulated process and recognize the influences of existing knowledge on perception, attention, and learning. Thus, the similarities between what Piaget saw as development and what contemporary theories see as learning are considerable.

We think that the ULM, more so than most other contemporary learning theories, shares Piaget's concern with understanding knowledge and intelligence as tied to the biology of a living organism. Memory in the ULM is not a "blank slate." Both working memory and long-term memory are neurological entities whose biological properties interact with and constrain what the senses take in from the environment. The ULM has replaced Piaget's mechanisms for development of advanced knowledge, with a set of mechanisms anchored in neural learning for developing chunks, procedures, and larger integrated networks of these. Overall, however, the ULM's view of intelligence as being a product of how knowledge is structured and organized is quite similar to Piaget's.

In education, the most prominent aspect of Piaget's theory has been the notion of stages. Piaget proposed that the development of thinking ability proceeded through a series of identifiable and distinct stages. Stage change was due to equilibration which produced qualitative shifts or restructuring of knowledge. This discontinuous process of restructuring was contrasted with incremental, continuous knowledge change produced by learning. Piaget proposed four stages: sensory-motor operations characteristic of infants, pre-operational, characteristic of children age 2–6, concrete operations characteristic of children age 7-adolescence, and formal operations characteristic of adolescents and adults.

The stage notion, however, has been the most misunderstood and misapplied aspect of Piaget's theory in education. Piaget proposed that his stages had a temporal sequence; they occurred successively over time, one after another, and in fixed order. He noted that, in the typical case for Western Europeans, these stages occurred at typical ages as noted previously. In applications of Piaget in education, most of the focus was placed on the age boundaries of the stages. Piaget himself never proposed that there were fixed age boundaries to his stages. He only asserted that they occurred in fixed order. Unfortunately, in schools, the age boundaries of Piaget's stages were often translated into a "readiness" boundary. It was thought that students couldn't be taught some content because they were in the wrong stage with stage defined as a specific age. Piaget certainly never saw the typical age boundaries of his stages as being constraints or indicators of readiness. He saw stages of thinking as constraining some types of learning, especially how concepts might be interpreted and understood. Whether students of any age could learn something, however, was not a function of their age; rather it was a function of their stage.

In the ULM, learning is "constrained" by prior knowledge. Prior knowledge is what allows a student to make sense of what they are learning and provides the expansions of working memory capacity needed to construct more elaborate chunks and interconnected networks. This constrains learning in much the same way that Piaget talked about a child's developmental stage constraining learning, or Vygotsky talked about the "zone of proximal development." One cannot understand fully the material that is too far beyond one's current level of understanding. In the ULM, this phenomena works through the prior knowledge effect.

In the ULM, we are concerned with knowledge growth in specific content areas and subject matter domains, especially those domains associated with formal schooling. Piaget always acknowledged that growth of knowledge and development of what we call expertise in specific subject matter was due to learning. He even recognized that children could acquire very high levels of expertise and thinking capability in specific topics or domains, so he would not have been concerned or surprised by demonstrations that high levels of thinking could be "taught" for specific content.[26] Piaget was concerned with global patterns of thinking and with the development of these global patterns. The ULM simply doesn't deal with knowledge at this global level.

In the ULM, all learning of specific subject matter knowledge is due to the mechanisms we have described previously. We take no specific position on whether stage-like change in global knowledge or thinking occurs. Work in connectionist/neural net modeling, however, has shown that global development in the Piagetian sense can be produced by computational and neurological mechanisms like those in the ULM.[27] From the perspective of the ULM, these processes, if they exist, would have little, if any, effect on learning as we have described it. We also make no claim that learning produces any type of change in a global pattern of thinking. A child learning algebra becomes more expert and skilled in algebra. She may even exhibit what Piaget called formal operational thinking in algebra. This implies nothing about her expertise in other subject matter, or whether or not she thinks formal operationally in general. Our position in the ULM is that, if stage-like developmental progressions do exist, knowledge acquisition in a content area would not be constrained by developmental stage and that developmental stage would not be a product of learning in a specific subject area.

Contemporary developmental theories have generally moved away from strong stage models as proposed by Piaget. In cognitive psychology, there is considerable convergence between current developmental theories and learning theories. There is general agreement that Piaget's equilibration mechanism probably is generally accurate but not specific enough to be a strong theory. Most contemporary developmental theories don't ascribe the same level of universality to global thinking as Piaget. Development is now viewed as both global and domain specific. Few still believe that some type of unitary "stage" characterizes all of a person's thinking across all domains. Contemporary developmental and learning theories, including the ULM, generally see knowledge as constructed by an active learner as opposed to passively received. Excellent general overviews of contemporary developmental psychology can be found in Flavel et al., "Cognitive Development" and Moshman "Adolescent Development."[28]

As with stages, we see no incompatibility between the ULM and any developmental mechanism that might be present. In the ULM, learning operates through the mechanisms we have described. There is no other influence. So learning would not be affected by a developmental mechanism, except to the extent that some developmental process could change knowledge in long-term memory independently from the learning mechanisms we have described. Such a change would influence the prior knowledge effect by altering existing knowledge. In any event, that would not change how learning happens, it would only change the prior knowledge being drawn upon. So the processes of learning described in the ULM would remain the same.

## Vygotsky – ZPD; Social Construction

As noted, the ULM suggests that, *for efficient learning there is an optimal content difficulty for new material that is to be learned*. You've probably already heard of this under the label, Vygotsky's zone of proximal development.[29] What the ULM does is make the requirements for being in the zone of proximal development more explicit. That is, the material to be learned must fill or nearly fill the learner's working memory without exceeding the learner's working memory capacity. This intimately ties the "zone of proximal development" to the learners' prior knowledge, because in the ULM, prior knowledge is the dominant influence on how much working memory capacity one has.

You've probably heard the term *social constructivism*, perhaps also connected with Vygotsky's name. Vygotsky noted that certain types of knowledge were not properties of the physical environment (that is, not sensory knowledge). Some knowledge was symbolic; a product of human thought and creation. This included things like the meaning of words, moral codes and laws, our theoretical explanations for phenomena in the world, such as the laws of physics, knowledge of mathematics, stories, art, music, and literature. Vygotsky noted that this symbolic knowledge was a social construction. It was something created and made meaningful by social agreement among people. Socially constructed knowledge is not objective; its "truth" or accuracy derives from rules and relationships within the socially agreed symbol system. As a result, Vygotsky argued that symbolic knowledge based on socially constructed meanings could only be acquired through social transmission. It is not possible to acquire this knowledge from direct interaction with the physical environment as this knowledge is a property of human society, not a property of the environment.

Social interaction occurs everywhere. A considerable amount of our socially constructed knowledge is acquired from interactions in the home between parents and children and siblings, or from peers in social settings, or from other adults in everyday life. Probably everything that we come to know as "common sense" is acquired in these informal settings. At a somewhat more formal level, for most of human existence, work skills were learned "on-the-job," passed down from experienced workers or "master" craftsmen to beginners or apprentices. This on-the-job experience included not just physical skill building but gaining understanding of the "ways of thinking" about phenomena in the particular job, craft, or profession. Anyone working in a large organization is aware that each has its own unique "corporate culture." Similar socially constructed cultures of knowledge and meaning are central to all organized social groups from athletic teams to religious orders.

Recognition of the need for social transmission of symbolic, socially constructed knowledge is a key reason why formal schools were created. Our store of knowledge has increased and become more formalized into advanced symbol systems like written language, higher mathematics such as calculus, and scientific theories. These are not likely to be learned as part of everyday or even "on-the-job" social experiences. Schools were created to provide ways to better and more systematically transmit this knowledge.

The ULM does not deny that symbolic knowledge is socially constructed. The ULM, however, is a model of learning from the perspective of an individual. New knowledge and skills may be created or discovered in social groups, and that new knowledge may even be encoded into an artifact such as a book. From the perspective of the ULM, however, this socially created knowledge and skill have not been learned until they have entered the mind of an individual, be he or she a member of an originating social group that created the knowledge or someone engaging with an artifact containing that knowledge (like a book). Learning occurs when the neurons in the brain of a person change. This requires that socially constructed knowledge ultimately effect change in an individual.

In education, Vygotsky's social construction of knowledge has been used to promote particular instructional approaches such as collaborative/cooperative learning, scaffolding, mentoring, and apprenticeship. Whether this is actually justified is problematical. Because knowledge might have originally been socially created does not imply that it is best taught through "social" learning or instructional methods like collaborative group learning. Neither does the common informal transmission of everyday common sense knowledge or existence of "on-the-job" training imply that these are the best ways to transmit this knowledge. Vygotsky himself did not privilege instructional methods that mirrored either the social knowledge construction process or indirect transmission of everyday knowledge. He provides many examples of direct instruction by teachers including lectures as ways to teach and transmit socially constructed knowledge in schools.[30]

We would concur with Vygotsky concerning instructional methods. As we will discuss in subsequent chapters, many instructional approaches are consistent with the ULM, including the collaborative learning, scaffolding, and apprenticeship approaches commonly associated with social constructivist approaches. The ULM also recognizes that students can interact together and interact with teachers in ways that socially construct new knowledge and understanding. Learning may occur in a social context and be helped by teachers, peers, and others. Whether any of these methods are good or bad is not a property of the method, it is a property of how it is used.

Some final comments about the ULM and constructivism. Constructivism is a term associated with Piaget[31] and especially Vygotsky.[32] At its core, two things describe the ULM. First, learning involves rewiring within the learner; no wiring for knowledge pre-exists only to be revealed by some developmental, environmental, or other means. In that sense, all knowledge (neuronal rewiring) that we have discussed in the previous chapters is constructed. It is always the result of the transformations and connections built in working memory. In Chapter 4, we even noted the especially constructive processes that occur during problem solving and critical thinking that can lead to unique new knowledge constructions. The ULM is "constructivist" because the neural connections in the brain are based on plasticity that constructs the unique connections between neurons. Second, like other constructivist theories, the rewiring that we undergo as human learners with respect to acquiring the symbolic socially constructed knowledge taught in schools requires our active participation. It is true that our autobiographical lives experience effortless, if fragile, recall of our daily experiences. It also is true that, under special circumstances, we can invent environments in which important learning is achieved incidentally, say, through playing games in which the player must repeatedly attend to and apply rules that otherwise would be part of a more traditional school curriculum. In the end, most learning that society expects from schools requires effort on the part of the students.

## Short-Term Memory

The notion of short-term memory predates that of working memory. Short-term memory referred to a temporary storage area where information was held for a brief period of time as contrasted with permanent storage in long-term memory. Working memory models have incorporated the notion of a temporary or short-term storage area or areas.[33] This is true of the ULM, as we defined working memory in Chapter 3 as containing a working memory storage area for temporarily and briefly holding elements of sensory input and/or knowledge retrieved from long-term memory. There has been debate as to whether short-term memory should be retained as a distinct construct separate from working memory. Engle, an early advocate of this distinction recently has revaluated the basis of this position.[34] Like other working memory models, the ULM integrates a consideration of the temporary and limited capacity of "short-term" memory into the broader operation of working memory. More technical debates about whether these are cognitively or neurologically unique "memories" do not affect how we describe working memory as operating in the ULM.

## Cognitive Load

*Cognitive load theory*, originally developed by John Sweller, is perhaps the closest current theory of learning to the ULM.[35] Like the ULM, cognitive load theory is grounded in the idea that human capacity is limited. Johnstone applied the notion of limited capacity to science education two decades ago.[36] Cognitive load theory lacks the ULM's explicit connection to specific working memory processes, but it shares the basic idea of the first principle of the ULM that learning is a function of how limited capacity is allocated. Cognitive load theory has also recognized the second principle of the ULM that knowledge affects capacity. Where it has diverged, has been in the overt consideration of the role of motivation as an influence on capacity that is a core principle of the ULM.

Cognitive load theory has focused most extensively on how aspects of the instructional setting and materials affect limited capacity. Sweller noted that the instructional setting placed various demands on the learners' available cognitive capacity that he referred to as load. In early work, two kinds of cognitive load were envisioned. The first involved load that resulted from the inherent difficulty of the to-be-learned material called *intrinsic load*. Intrinsic load was a function of how complex or difficult the material was and how much information needed to be stored in working memory and processed. Think of the difference between learning a specific fact and learning how to balance a chemical reaction. In ULM terms, learning through the second rule by repetition would have less "load" than learning through the third rule by making connections. The second, *extrinsic load*, consisted of features of the learning environment that were not themselves part of what was to be learned, but demanded use of cognitive capacity. Typically, extrinsic load was encountered as the result of poor instructional design or distracting features in the design. Extrinsic load decreases learning because the capacity allocated to deal with it decreases the capacity available for learning. For example, putting everything on one page or one screen leads to better overall outcomes than having the learner move back-and-forth between two pages, or two screens, or a page and a screen. The ULM takes a similar view that anything that reduces allocation of working memory capacity to the learning task will decrease learning.

In more recent work, a third type of load called *germane load* has been identified. Germane load is a companion to intrinsic load and reflects a distinction similar to that in the ULM between storage and processing. Intrinsic load is now viewed as a storage load consisting of the number of unique things that must be learned and therefore held in working memory, and germane load is the load from needing to process the stored information, such as making connections or transformation.[37] As in the ULM, working memory capacity needs to balance space for both storage and processing. Consider the model of slots. Let's say you have one slot filled with knowledge about angles and another filled with knowledge about triangles, two entities creating intrinsic load, and you need to pull them together – say to create the notion that the sum of the angles in a triangle is 180°. It is in this third slot that you are going to need to handle the germane load and start tying together those sets of notions.

Perhaps the single most important overall difference between cognitive load theory and the ULM is that the former remains almost universally silent with respect to learner motivation. Sweller's most recent book shows motivation as a single index topic that directs readers to a section entitled "Emotional vs. Cognitive Sources of Motivation."[38] That section points to two studies by Mayer suggesting that the inclusion of "seductive details" in learning materials negatively impacts learning.[39]

It is extremely unlikely that the ULM would have emerged from us had we not been very familiar with the work of Sweller and others in the area of cognitive load.[40] Virtually all of the instructional principles and suggestions derived by cognitive load researchers are compatible with the ULM. We see no reason to discuss this work in detail in this book. Readers are encouraged to see Sweller's book, *Efficiency in Instruction*.[41] Very recently, an entire edition of *Educational Psychology Review* was devoted to an exploration of the frontiers of cognitive load theory.[42]

## "Ah, Ha" Moments Involve Special Marking for Later Retrieval

We've all had "Ah, ha" moments (sometimes attributed to Archimedes upon figuring out how to measure volume by displacement and called "Eureka" or "I have found it" moments).[43] There is the moment when you have just finished studying and realize that you are "ready for the test." There is the moment when you finish cleaning up after painting a room and can say to yourself, "That's done, now I can do something that is fun." For the most part, when teachers speak of "Ah, ha" moments, these examples are not the ones in question.

There is copious anecdotal support for special events in learning called "Ah, ha" moments when, by obvious emoting of one type or another, the learner says, "Now I get it." In the literature, especially the conceptual change literature, "Ah, ha" moments have been viewed as reflecting qualitative shifts in thinking that result from restructuring of knowledge, similar to what Piaget proposed about cognitive development. Restructuring theories have generally proposed that qualitative shifts in knowledge result from a specific "restructuring" learning mechanism that produces qualitative change distinct from the presumably continuous change produced by regular learning mechanism, although these mechanisms have not been well defined in the previous literature.[44]

As the ULM was being developed, we at first attributed "Ah, ha" moments to routine chunking.[45] This was based partially on work in cognitive modeling that has failed to find qualitative restructuring mechanisms.[46] We now believe that "Ah, ha" moments result from something different. Back in the knowledge chapter, we talked about how one of the key processes of working memory is to connect input in working memory storage together in different ways. We noted that these new connections, which arise during episodes of problem solving or critical thinking, create or construct new knowledge. Clearly, any new knowledge arising from one of these constructions would be "qualitatively" different from the way that knowledge was interconnected previously. In the ULM, repetition is the quantitative learning mechanism and connection is the "qualitative." We would hold that the ULM's third principle of learning is the "restructuring" mechanism alluded to in the previous literature.

When we become aware of newly constructed knowledge, we can experience an "Ah, ha." As we have noted previously, working memory processes, including creating new connections, do not have to be conscious. "Ah ha" moments especially seem to emerge after an initially unsuccessful attempt to consciously construct a solution that is subsequently pursued unconsciously. These resolutions are greeted with glee when we are finally aware of the resolution. One might ask, "Why this moment of glee?" We have previously discussed the role of emotion in marking knowledge for storage and enhancing retrieval. Our experience of emotion during an "Ah ha" may be a way of marking the newly constructed knowledge to insure storage in a way to enhance later retrieval.

There is experimental neurological evidence for these insightful moments. For example, when learners are presented with triplets of words such as date/alley/fold and asked to discover a word linking them – in this case "blind." Using both functional magnetic resonance imaging (fMRI) and electroencephalogram (EEG) measurements, sudden bursts appear at the instant that the solution emerges.[47] Subjects are asked to indicate whether they solved the problem with or without insight. Insight is described as coming to an "impasse" in solving and feels as if he/she has moved on followed by a moment in which the solution suddenly emerges. Indeed, neural regions not involved in the routine problem solving are indicated for the insightful solutions.

## Ordinary Learning Moments Require No Special Marking

There is an aspect about "Ah, ha" events that should be emphasized. They are typically reported as happening after an unsuccessful search. Generally, we report them after we think we have stopped consciously searching. So, the search that was successful must have been a subconscious search. With a model like the ULM, you will be tempted to think that you can control four slots and that you can consciously load them. That's not how it works. The allocation process is only partially within our conscious control. The details of most of the processes we use remain hidden from us even as we use them.

Are "Ah, ha" moments good or bad? There certainly have been some of these moments during the development of the ULM. For example, there was the emergence of the notion that motivation amounts to working memory allocation. This was followed years later by the realization that neuroscientists speak of the top-spot in working memory using the term focus of attention, and thus all of the work they had done in terms of focusing attention could then be revisited from the perspective of motivation.[48]

It certainly is not a sure thing, however, that the good feelings that come from the "Ah, ha" moment are worth the inefficiencies connected with designing instruction based upon discovery and "Ah, ha" moments. We can ask students to "think" about something or design problem solving activities that require unique applications of knowledge, but we can't guarantee that a student will actually be able to create meaningful new connections. We once had a conversation with a college classroom teacher who developed "learning cycle" laboratory activities. It was considered to be a bad activity when all students "got it" immediately. It was worse, however, when no students got it.[49]

## Savants: Prodigies

During the earliest stages of the development of this book, one author said to another, "But what about savants?" At that time, both of us held the folklore-entrenched view that savants were very unique, but important, special cases where knowledge seems to appear without having been learned in a traditional way.

Persons with savant syndrome show generally low skills and usually have problems functioning but display strong and unusual skills in unique areas (e.g., recalling day or weather given date, piano, painting). As noted, it once was thought that these skills emerged spontaneously giving support to the claim that humans are somehow pre-wired and that savants are able to tap into that wiring. According to the ULM, *no human is prewired with an advanced skill*. That is, the ULM insists that none of us can spontaneously drive or play a piano; these are skills that *must* be learned. Whatever pre-wiring humans may have, the ULM sees that pre-wiring as being rather minimal. More recent and thorough study suggests that savant skills are an outcome of much more conventional instruction: practice with feedback. A considered current view of the phenomenon is summed up as: "A person with normal brain function could become a calendar prodigy; it is just very unlikely that they will find the process rewarding enough to persevere to this extent."[50]

The reason this is important to note is that, if just one savant were found with advanced skills that appeared in situ without being learned, then the ULM could not be correct as a model. In the ULM, microstructure is constructed as opposed to being "revealed" from some otherwise, hereditary, pre-existing states. Indeed, it seems that special skills only emerge through practice. Proportional reasoning as a general skill emerges in students as the result of practice with phenomena and materials in which this concept applies, for example.

There are those regarded as prodigious geniuses such as the musician Mozart and the chess master Fisher. Careful studies of the lives of prodigies always seem to show external encouragement, access to effective coaching, and materials such as a library. While it was said that Mozart wrote music in singular bursts (i.e., put directly from "mind" onto paper without editing), the evidence is that he edited over long time periods in a fashion similar to that of most composers.[51] Much literature points to the notion that, in order to develop expertise, about ten years of study must be completed.[52] The so-called 10-year rule appears to have applied to Mozart and Fisher as well as to other elite experts.

### *Special Memory*

There are reports of some truly unusual people with respect to memory. For example, AJ remembers essentially all of her life experiences.[53] "Her memory is 'nonstop, uncontrollable, and automatic.' AJ spends an excessive amount of time recalling her personal past with considerable accuracy and reliability." Some suspect that she spends a great deal of time rehearsing as we would when trying to achieve rote memorization. In the absence of considerable effort, ordinary episodic memory is a fragile and fleeting thing for most of us. Rather than having this unusual ability to recall as a gift, AJ reports herself to be dysfunctional and seeks help. Other reports of really good memories, variously called eidetic memory or photographic memory, appear frequently but most often are surrounded by controversy.[54]

Experts often acquire very powerful memory. They can attend a seminar and recall nearly all of what was said, although not verbatim. This is an example of just how important prior knowledge and motivation are. Most likely, they already know much of what is said and think so often about that which is new that they are really rehearsing that content over and over. Those are characteristics of many experts and how they deal with information. Two of the authors are thought to have good memories. One, DS, is able to recall a wide range of content with some but not much effort. The other, DWB, was known for being able to call 750 of 1,000 students from lecture class by face on campus but outside of his classroom. Rather than the result of a special gift, this recognition resulted from hour upon hour of study using photographs arranged in grids that matched student's places in laboratory. It included immediate rehearsals in the teaching laboratory followed by engaging the students in conversation – something that teachers in much smaller classes but without laboratory sessions have no opportunity to practice.

## Multiple Intelligences

A very popular notion developed by Gardner and rooted in studies of geniuses, savants and aphasics is multiple intelligences.[55] In this notion, intelligences may be divided into subcategories (logical-mathematical, spatial, musical, interpersonal, etc.) and individuals may essentially have more of one than another. No agreed upon measures of these sub-categories have emerged that are not well-predicted by measures of fluid intelligence, however.[56]

At the same time that no serious science has emerged to support multiple intelligences, this remains a notion warmly embraced by classroom teachers. After all, it stands the test of time: we all know people who are good at some things but bad at others. The ULM accounts for these differences in terms of prior knowledge. Further, as we become good at things, we usually become good at becoming better at those same things. We develop what Bandura calls virtuous cycles.[57]

We've cited some important evidence about expertise developed by Bloom and his colleagues and published in *Developing Talent in Young People*.[16] They define talent as " . . . an unusually high level of demonstrated ability, achievement, or skill in some special field of study or interest."[58] They go on to assert: "Although we cannot be certain of this, we believe that only a small percentage (10% or less) of these talented individuals had progressed far enough by age eleven or twelve for anyone to make confident predictions that these would be among the top 25 in the talent field by the ages of twenty to thirty. . . . Even in retrospect, we do not believe that perfecting of aptitude tests or other predictive instruments would enable us or other workers in the field to predict high-level potential talent at these early ages."[59]

Since Gardner is generally regarded as the principal advocate of multiple intelligences, it is appropriate to consider his writings in more detail. He describes multiple intelligences in terms of "biopsychological potential," cites genetic proclivity for diseases, extrapolates this heritability to intelligence, and then emphasizes assumptions of many scientists that intelligence is heritable by as high as 80% based on IQ tests.[60] While Gardner does not deny the possible influences of environment on the development of intelligence, his theory does not paint a promising picture for those who would exceed their "potential." The contrast between these views and the ULM are many. The ULM interprets learning in terms of neuronal changes: that neurons are neurons (not music neurons or aesthetic neurons), and that prior learning greatly impacts one's ability to work as what Bloom might call a "talented" person.

In the end, this probably doesn't matter. In *Creating Minds*, Gardner identifies a small sample of highly recognized individuals (e.g., Einstein, Gandhi) in which he cites the so-called 10-year rule. (The 10-year rule, generally regarded as accepted, is that it takes about 10 years of serious study with appropriate teaching, mentoring, and support to achieve expert status in virtually all fields.)[61] Gladwell calls this the 10,000 h rule.[62] The amount of time spent practicing distinguishes excellent from good musicians.[63] Thus, even if one believes that there are multiple intelligences, this in no way alters the amount of time and effort required to develop expertise.

One thing in Gardner's writing is especially noteworthy, namely, that people at the top of their talent areas frame experiences in a way that is positive.[64] Perhaps it can be summed up as the ability to learn from one's mistakes.

## Learning Styles

A learning style is thought of as some combination of characteristics (cognitive, affective, psychological) related to how one interacts with one's learning environment.[65] This idea is rooted in the belief that humans differ in the sense modality of stimuli from which they learn best – take in, remember, and process new information.[66] Many studies have failed to find evidence for such styles. For example, Krätzig and Arbuthnott conclude: "The present results suggest that people's intuitions about their learning styles may be incorrectly attributed. Specifically, such styles may indicate preferences and motivations rather than inherent efficiency at taking in and recalling information through specific sensory modalities."[67] Coffield et al. present a critical review.[68] What is the take of the ULM on learning styles? First, convincing data for the existence of learning styles is not at hand. Based upon the ULM fifth rule that "learning is learning," we suspect that there are no biological constraints placed on people – that nearly any of us could end up emphasizing nearly any style (if such a thing really exists).[69] In short, we are skeptical of the existence of this phenomenon in a meaningful, measurable way. If such a phenomenon does exist, it certainly can be ascribed to learning the "style" (i.e., prior knowledge) and need not invoke some special inherited uniqueness (as in one of the growing list of multiple intelligences).

It is certainly true, however, that students think of themselves as having different learning styles. Whether objectively true or not, students can be heard saying things like "I learn better when I can hear about it in class than reading about it," or "I can understand it better when I read about it." If students think of themselves as learning better with certain content or media than others, then given what we have previously discussed about expectancies, it is reasonable to think that students develop particular motivational preferences toward different ways of learning. It is probably more proper to talk about "motivational" style than learning style. Given what we discussed in the motivation chapter, it is easy to see that if a student feels more confident or expects to learn better with visual material than through listening, he/she is likely to have more motivation and more effective allocation of working memory with visual materials.

## The Executive

The notion of an executive probably evolved from tradition, possibly the tradition of a homunculus, rather than from a body of data that required explanation.[70] If you search this book, you'll not find the term executive used in the sense of CEO or "decider." The original model of Baddeley and Hitch (1974) had three parts: a central executive, a phonological loop, and a visuospatial sketchpad.[71] In 2000, Baddeley found the need to add an "episodic buffer."[72] The ULM does not make use of any of these. Instead, anything in memory is potential fodder for working memory. If this is the case, how are decisions made? In some ways, these arguments go back to the homunculus arguments: "One may explain (human) vision by noting that light from the outside world forms an image on the retinas in the eyes and something (or someone) in the brain looks at these images as if they are images on a movie screen. . . ."[73] That voice that we hear speaking to us as we decide things fools us over and over. Because of the way neural networks work, we don't need any such "decider" in the ULM.[74]

As we discussed previously in Chapters 3 and 4, no special inductive or decision making neural or cognitive mechanisms are required to explain how working memory operates or how knowledge is stored. Attention, repetition, pattern matching, and the other mechanisms of the ULM operate without the need for a supervisor or any oversight system. While it is proper to talk about a whole person as making decisions, self-regulating, or controlling their working memory processing, this is different from the notion of a cognitive or "inside the head" executive system. We have noted that the working memory, long-term memory, and motivational cognitive and neurological processes of the ULM do not require controlled processing by the person. They can work automatically. Similarly, they do not require a cognitive executive to initiate or monitor them.

## Gender Differences

There do seem to be differences between men and women in terms of cognition. Generally speaking, these differences are small. Several decades ago, gender differences in, say, mathematics scores were large and explanations for those differences many. The title of a recent *Science* Education Forum says it all: "Gender Similarities Characterize Math Performance."[75] We do not doubt for a moment that gender differences exist and that they may be important. As with nearly everything else we assert in the ULM, however, we come down on the largest factor in creating these differences as being differences in knowledge (i.e., prior learning).[76] There are gender differences in reported self-efficacy that we discuss later.[77]

## Primary Versus Secondary Learning

A special issue of the Educational Psychologist entitled "Evolution of the Educated Species" appeared late in 2008 (Volume 43, Number 4). The central paper by Geary, based on earlier work, incorporates many novel ideas.[78] A key notion is that learning can be divided into biologically primary and biologically secondary categories. Biologically primary categories refer to learning associated with specialized neurological processing areas in the brain that have evolved to optimize speed of learning and processing. We have mentioned some of these types of areas previously, like the specialized sensory processing areas for visual, auditory, and other sensory input and the motor cortex areas specialized to specific peripheral muscle groups like the fingers. Biologically primary categories can also exist for higher functions like language or at least oral language. Geary notes that these specialized areas have evolved to be sensitive to specific learning inputs related to their specialty processing.

The biologically secondary category refers to learning where no specialized neural area exists to process that knowledge. This would include basically all of what Vygotsky called socially constructed and transmitted knowledge which includes pretty much everything we teach in school. There simply aren't specialized brain areas for chemistry, or social studies, or algebra, or literature. Learning about these occurs in the brain's general non-specialized areas or as Geary has noted, by piggybacking on and repurposing one of the biologically primary areas.

A classic example of this distinction is language. Oral language is a biological primary. It is learned early in life, during infancy. Being in a language using environment seems to be sufficient for learning. Extensive special motivation does not seem to be required; in fact, motivation seems to be intrinsic. There are underlying specialized language areas in the brain that facilitate this processing through specialized functioning. Learning written language, reading and writing, however, is a biologically secondary category. There is no specialized brain area for written language; written language appropriates the oral language areas and repurposes them. Learning usually requires explicit instruction and deliberate motivation. Learning is not certain. Virtually all humans become proficient in their native oral language. Reading and writing are far less universal. Even where most of the population is literate, there are wide variances in proficiency.

Geary's arguments are an extension of older arguments about heredity and nature versus nurture that we have discussed previously. Geary's categories don't really affect the premises of the ULM. Learning in both biological primary and biological secondary areas follows the same neurological learning principles we have described previously. Neurons are strengthened in the same ways whether in a specialized or general area of the brain. Because biologically primary areas are sensitive only to certain kinds of stimuli, their frequency counts achieve accuracy faster. Geary argues that attention is drawn to sensory inputs associated with biologically primary categories. We also appear to be naturally drawn to or motivated to learn biologically primary knowledge. He argues that much of everyday learning, what we might call common sense or general knowledge, is associated with biologically primary categories that have evolved over time to reflect the common aspects of the human physical and social environment.

Geary also argues that school learning deals primarily with knowledge that is biologically secondary. The subject matter being learned in school is not going to get a boost of efficiency or motivation from specialized neurology. It will require all of the ULM rules we have discussed. This distinction also has instructional implications. A number of situated cognition, apprenticeship, and constructivist instructional approaches have tried to use everyday learning as a model. They argue that if we could make school more like everyday experience, or instruction in school more like the informal approaches used in everyday settings, students would learn more easily and be more motivated. Geary argues that this is not likely to be the case. Everyday learning is different not because it occurs outside school, but because it is biologically primary. This biological primary learning will not transfer to the biological secondary learning required for school subjects.

## History and Background

The ULM did not emerge spontaneously; the search for a unified model is not new. Allen Newell gave a series of lectures at Harvard in 1987 and wrote *Unified Theories of Cognition* based on them.[79] He suggests that a unified theory must offer three advantages: explanation, prediction, and prescription for control. He indicates that a theory of cognition must deal with a range of issues from problem solving through language to daydreaming. The model he advanced was based upon his work with *SOAR*, an architecture for general intelligence first substantiated as an artificial intelligence computer system.[80] So is the ULM a unified theory of cognition in Newell's sense? The answer to this is, no. While the ULM does well in terms of explanation, prediction, and control prescription, it certainly is far from being instantiated as an operating artificially intelligent computer architecture. However, we did not set out to develop a fully realized model of cognition. We set out to create a synthesis that could unify what is known about learning, particularly classroom learning, into a workable model that fully described the process of learning.

It is remarkable how close others have been to describing what essentially is the ULM. For example, Bereiter wrote (shown below with his citations removed)[81]:

> "A contextual module is not just related to a context. It embodies the person's whole relationship to that context. The influence of culture, that initially may have been identifiable in particular beliefs, goals, and rules of conduct, can now be only globally assessed on the module as a whole. There is no longer a separate representation of the context. Instead, that representation is implicit in the whole structure of person-environment relations embodied in the module. This is what situated cognition would mean in a theory based on contextual modules. It would be an emergent property of modularity rather than an attribute of the learning process itself." [p. 613–614]
>
> "There seems no reason to suppose that any special process goes on in the development of contextual modules that is different from the kinds of processes dealt with in theories of learning and development. Computer-implemented theories have demonstrated a number of processes that could contribute to modularization. Chunking forms larger units from mental contents that are repeatedly activated together. Chunks could form across as well as within components, for instance, combining the representation of a situation with its associated affect and with goals typically pursued in that situation. Reduction to results stores the results of procedures as declarative knowledge, thus eliminating the need for the procedure; one does not need to keep solving the same problems. Finally, compilation produces streamlined procedures that eliminate calls for explicit declarative knowledge or representations of situations, because these become implicit in the procedures. What is novel in the idea of contextual modules is not the processes involved but the result. The result is a cognitive unit having properties of real human significance that are not possessed by smaller psychological units." [p. 614]

Based on this, it is clear that Bereiter anticipated chunks that were really complete up to the point of including their own motivation. Two extremely highly regarded researchers, Ericsson and Kintsch, struggled with the limited capacity of working memory and constructed the notion of "long-term working memory."[82] They expressed their dilemma as:

> On the basis of a century of laboratory research on memory many theorists have concluded that LTM can meet neither the criteria of speed and reliability for storage nor those for retrieval.

Schraw realized that ability, prior knowledge, and motivation all were important in understanding successful learning, but his model treated them separately and spoke of how one aspect could "compensate" for another without appreciating the biological underpinnings that made this possible.[83]

> We assume that each of the modules [knowledge, ability, motivation] contributes directly or indirectly to learning, and compensates for potential deficits in other components. Specifically, we assume that cognitive ability is related to learning both directly and indirectly via knowledge and regulation. Strategies and metacognition typically co-develop and are strongly related. Knowledge and regulation are related to motivation. Cognitive ability is not related to motivation. Knowledge, regulation, and motivation each are related directly to learning.

Mindset matters. How could researchers, for nearly two decades, be so close to creating a unified model? Perhaps this is because of the prior learning we bring to issues. For example, the Baddeley and Hitch paper on working memory, while seminal, included notions of separate buffers and an executive.[84] In fact, in order to account for some data, Baddeley added the notion of an "episodic buffer" as recently as 2000.[85]

We certainly are not the first to call for better integration of understandings about motivation with those about cognition. Such eminent researchers as Simon and Pintrich both wrote extensively about this need, but never developed models at the same level of detail as the ULM to achieve such integration.[86]

The biggest challenge we faced in developing the ULM was in putting parts of the old explanations and theories aside while remaining faithful to accounting for the data that led to those models.

## Our Purpose in This Chapter

We obviously believe that the ULM is a powerful model that accounts for essentially all that is known about learning. The purpose of this chapter, then, has been to account for the data that others cite when arriving at their models without using those models but using the ULM, instead. So, ability becomes a mix of working memory capacity and prior knowledge rather than fluid and crystallized intelligence. Apparent jumps in skills become chunks rather than stages and are accounted for in the ULM in terms of prior knowledge. Matching learners to instructional materials becomes a question of working memory capacity and prior knowledge rather than zone of proximal development. Knowing people with vastly different skill sets becomes prior knowledge rather than multiple intelligences or learning styles. Those neurons in the cerebral cortex “learn” things in the same way no matter which cortical tissue mass or lobe they are in. “Ah, ha” moments arise when chunks are activated at the same time in working memory, although they rarely if ever have been activated at the same time before.

In a few but important cases we depend upon better data. Savantism emerges as an example of knowledge resulting from learning rather than special gifts or wiring, a view that contrasts with part of the generally accepted lore of learning.

The ULM has something going for it that scientists always strive for: parsimony. That is, we make fewer assumptions than nearly any other models. We assert that learning depends upon your working memory: how much you’ve got of it (capacity), how you’ve used it in your past (prior knowledge), and how you are using it now (motivation). The ULM not only accounts for extant data, but it implies both ways to test the model and to apply the model.

## Notes

1. http://en.wikipedia.org/wiki/IQ (Accessed March 23, 2009).
2. Spearman, C. (1904). General intelligence objectively determined and measured. *American Journal of Psychology*, *15*, 201–293.
3. Harrison, P. L., & Flanagan, D. P. (2005). *Contemporary intellectual assessment: Theories, tests, and issues*. New York: Guilford Press.
4. Horn, J. L., & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized general intelligences. *Journal of Educational Psychology, 57*, 253–270.
5. Colom, R., Rebollo, I., Palacios, A., Juan-Espinosa, M., & Kyllonen, P. C. (2004). Working memory is (almost) perfectly predicted by g. *Intelligence, 32*, 277–296; Kyllonen, P. C. (1996). Is working memory capacity Spearman’s g? In I. Dennis & P. Tapsfield (Eds.), *Human abilities. Their nature and meaurement*. Mahway, NJ: Lawrence Erlbaum; Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory*. Cambridge: Cambridge University Press.
6. Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences, 105*(19), 6829–6833.
7. Thompson, P., Cannon, T., Narr, K., van Erp, T., Poutanen, V., Huttunen, M., et al. (2001). Genetic influences on brain structure. *Nature Neuroscience, 4*, 1253–1258; Chiang, M. C., Barysheva, M., Shattuck, D. W., Lee, A. D., Madsen, S. K., Avedissian, C., et al. (2009). Genetics of brain fiber architecture and intellectual performance. *Journal of Neuroscience, 29*(7), 2212–2224.
8. Flynn, J. R. (1987). Massive IQ gains in 14 nations: What IQ tests really measure. *Psychological Bulletin, 101*(2), 171–191.
9. Devlin, B., Daniels, M., & Roeder, K. (1997). The heritability of IQ. *Nature, 388*(6641), 468–471; Richardson, K., & Norgate, S. (2005). A critical analysis of IQ studies of adopted children. *British Journal of Educational Psychology, 75*(3), 339–350.
10. This study involves groups of three – a pair of monozygous male twins (nearly 100% identical genes) and a brother (~50% gene overlap with twin). The title suggests that the twins were much more alike with respect to fMRI studies during problem solving. It does not point out that twins generally have much similar learning environments than do paired siblings. Also, twins generally learn to speak a bit later, on average, and they also are described as developing interpersonal communication schemes that only they perceive. It would be

important, therefore, to study large numbers of monozygous twins in which the differences were large in an attempt to tease out a better understanding of environmental influences. Koten Jr., J. W., Wood, G., Hagoort, P., Goebel, R., Propping, P., Willmes, K., et al. (2009). Genetic contribution to variation in cognitive function: An fMRI study in twins. *Science, 323*, 1737–1740.

11. Toga, A., & Thompson, P. (2005). Genetics of brain structure and intelligence. *Annual Review of Neuroscience, 28*, 1–23.
12. Plomin, R., & Kosslyn, S. (2001). Genes, brain and cognition. *Nature Neuroscience, 4*, 1153–1154.
13. Gladwell, M. (2008). *Outliers: The story of success*. New York: Little, Brown, and Company.
14. Colvin, G. (2008). *Talent is overrated: What really separates world-class performers from everybody else*. New York: Penguin Group.
15. Bloom, B., & Sosniak, L. (1985). *Developing talent in young people*. New York: Ballantine Books.
16. http://en.wikipedia.org/wiki/Matthew_effect (Accessed March 23, 2009); Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21*, 360–407.
17. Wattie, N., Baker, J., Cobley, S., & Montelpare, W. J. (2007). A historical examination of relative age effects in Canadian hockey players. *International Journal of Sport Psychology, 38*(2), 178.
18. Another book related to talent acquisition that appeared just as this book was going to press is Coyle, D. (2009). *The talent code. Greatness isn't born. It's grown. Here's how.* New York: Random House. The title of this book as well as its content is consistent with the notion that innate talent is much more myth than fact.
19. Bayliss, D. M., Christopher, J., Baddeley, A. D., Gunn, D. M., & Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology, 41*, 579–597; Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin*, *89*, 63–100.
20. See Newcombe, N. S. (2002). The nativist-empiricist controversy in the context of recent research on spatial and quantitative development. *Psychological Science. 13*, 395–401; Kagan, J. (2008). In defense of qualitative changes in development. *Child Development, 79*, 606–1624.
21. Geary, D. C., & Huffman, K. J. (2002). Brain and cognitive evolution: Forms of modularity and functions of mind. *Psychological Bulletin, 128*, 667–698.
22. Case, R. (1995). Capacity-based explanations of working memory growth: A brief history and reevaluation. In F. E. Weinert & W. Schneider (Eds), *Memory performance and competencies: Issues in growth and development* (pp. 23–44). Hillsdale, NJ: Lawrence Erlbaum Associates.
23. Kandel., E. R., Schwartz, J. H., & Jessell, T. M. (2000). *Principles of neural science* (4th Ed.). New York: McGraw-Hill.
24. See Piaget, J. (2003). PART I: Cognitive development in children: Piaget: Development and learning. *Journal of Research in Science Teaching, 40*(Suppl), S8–S18; Vosniadou, S., Baltas, A., & Xenia, V. (Eds.). (2007). *Reframing the conceptual change approach in learning and instruction*. New York: Elsevier Science.
25. Vosniadou, S., Baltas, A., & Xenia, V. (Eds.). (2007). *Reframing the conceptual change approach in learning and instruction*. New York: Elsevier Science
26. Wollman, W. (1984). Models and procedures: Teaching for transfer of pendulum knowledge. *Journal of Research in Science Teaching*, *21*(4), 399–415; Wollman, W., & Lawson, A. E. (1978). The influence of instruction on proportional reasoning in seventh graders. *Journal of Research in Science Teaching*, *15*(3), 227–232.
27. Elman, J. L., Bates, E. A., Johnson, M. H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development*. Cambridge, MA: MIT Press.
28. Flavell, J. H., Miller, P. H., & Miller, S. A. (2002). *Cognitive development* (4th Ed.). Englewood Cliffs, NJ: Prentice Hall; Moshman, D. (2005). *Adolescent psychological develoment: Rationality, morality, and identity* (2nd Ed.). Mahwah, NJ: Erlbaum.

29. Vygotsky's terminology includes the "zone of proximal development," or ZPD. (Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.).
30. Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.
31. http://projects.coe.uga.edu/epltt/index.php?title=Piaget%27s_Constructivism (Accessed April 5, 2009).
32. http://projects.coe.uga.edu/epltt/index.php?title=Vygotsky%27s_constructivism (Accessed April 5, 2009).
33. For example see Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation.* (Vol. VIII, pp. 47–90). New York: Academic Press.
34. Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin, 133*(6), 1038–1063.
35. Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*, 257–285.
36. Opdenacker, C., Fierens, H., van Brabant, H., Sevenants, J., Spruyt, J., Slootmaekers, P. J., et al. (1990). Academic performance in solving chemistry problems related to student working memory capacity. *International Journal of Science Education, 12*(2), 177–185; Johnstone, A. H., Hogg, W. R., & Ziane, M. (1993). A working memory model applied to physics problem solving. *International Journal of Science Education, 15*(6), 663–672.
37. van Merrienboer, J., Kester, L., & Paas, F. (2006). Teaching complex rather than simple tasks: Balancing intrinsic and germane load to enhance transfer of learning. *Applied Cognitive Psychology*, *20*(3), 343–352.
38. Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning: Evidence-based guidelines to manage cognitive load*. San Francisco: Pfeiffer. See pp. 116–118.
39. Harp, S. F., & Mayer, R. E. (1997). The role of internet in learning from scientific text and illustrations: on the distinction between emotional interest and cognitive interest. *Journal of Educational Psychology, 89*(1), 92–102; Mayer, R. E., Heiser, J., & Lonn, S. (2001). Cognitive constraints on multimedia learning: When presenting more material results in less understanding. *Journal of Educational Psychology, 93*(1), 187–198.
40. Cooper, G. (1998). Research into cognitive load theory and instructional design at unsw. http://paedpsych.jk.uni-linz.ac.at:4711/LEHRTEXTE/Cooper98.html (Accessed September 4, 2008).
41. Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning: Evidence-based guidelines to manage cognitive load*. San Francisco: Pfeiffer.
42. The first issue of volume 21 of *Educational Psychology Review* included seven papers. The introductory paper provided an overview (Ayres, P., & Paas, F. (2009). Interdisciplinary perspectives inspiring a new generation of cognitive load research. *Educational Psychology Review, 21*(1), 1–9). Three papers within were of special note. Sweller has begun attempts to apply CLT to the issue of creativity (Sweller, J. (2009). Cognitive bases of human creativity. *Educational Psychology Review, 21*(1), 11–19). Renkl addresses worked examples and heuristic problems (Renkl, A., Hilbert, T., & Schworm, S. (2009). Example-based learning in heuristic domains: A cognitive load theory account. *Educational Psychology Review, 21*(1), 67–78). Kirschner addresses issues connected to CLT and collaborative learning (Kirschner, F., Paas, F., & Kirschner, P. A. (2009). A cognitive load approach to collaborative learning: United brains for complex tasks *Educational Psychology Review, 21*(1), 31–42).
43. http://en.wikipedia.org/wiki/Archimedes (Accessed March 23, 2009).
44. Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*, 51–67; Vosniadou, S., Baltas, A., & Xenia, V. (Eds.). (2007). *Reframing the conceptual change approach in learning and instruction*. New York: Elsevier Science.
45. Early in the development of the ULM we realized that "Ah, ha" moments are unusual, and that ordinary learning and ordinary conceptual change happen without drama. From Ohlsson: "It follows that nothing extraordinary happens at the moment of conversion. . .." Ohlsson, S.

(2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20–40 (p. 32).

46. Anderson, J. R., & Schunn, C. D. (2000). Implications of the ACT-R learning theory: No magic bullets. In R. Glaser (Ed.), *Advances in instructional psychology: Educational design and cognitive science* (Vol. 5, pp. 1–33). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.
47. Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight, *PLoS Biol* (Vol. 2). http://www.plosbiology.org/article/info:doi/10.1371/journal.pbio.0020097
48. Knudsen, E. I. (2007). Fundamental components of attention. *Annual Review of Neuroscience, 30*, 57–78. As you read this review, think about attention as the premier slot in working memory and the rest of the slots devoted to deciding which among the potential slots is to be the focus of attention.
49. Robert Silberman (personal communication, August, 1984).
50. Thioux, M., Stark, D. E., Klaiman, C., & Schultz, R. T. (2006). The day of the week when you were born in 700 ms: Calendar computation in an autistic savant. *Journal of Experimental Psychology: Human perception and performance*, *32*(5), 1155–1168.
51. Ross, A. (July 24, 2006). The storm of style: Listening to the complete Mozart. *The New Yorker*. http://www.newyorker.com/archive/2006/07/24/060724 crat_ atlarge (Accessed March 23, 2009).
52. http://en.wikipedia.org/wiki/Expert (Accessed March 18, 2009).
53. Parker, E., Cahill, L., & McGaugh, J. (2006). A case of unusual autobiographical remembering. *Neurocase, 12*(1), 35–49.
54. http://en.wikipedia.org/wiki/Eidetic_memory (Accessed March 23, 2009).
55. Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.
56. Waterhouse, L. (2006). Multiple intelligences, the Mozart effect, and emotional intelligence: A critical review. *Educational Psychologist*, *41*(4), 207–225.
57. Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: W. H. Freeman.
58. Bloom, B., & Sosniak, L. (1985). *Developing talent in young people*. (p. 5) New York: Ballantine Books.
59. Bloom, B., & Sosniak, L. (1985). *Developing talent in young people*. (p. 533) New York: Ballantine Books.
60. Gardner, H. (1993). *Multiple intelligences: The theory in practice. A reader*. (p. 51; p. 36) New York: Basic Books.
61. Bloom, B., & Sosniak, L. (1985). *Developing talent in young people*. (p. 537) New York: Ballantine Books; Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363–406; Howe, M. J. A. (1999). Prodigies and creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 431–448). Cambridge: Cambridge University Press.
62. Gladwell, M. (2008). *Outliers: The story of success*. New York: Little, Brown, and Company.
63. Sloboda, J. A., Davidson, J. W., Howe, M. J. A., & Moore, D. G. (1996). The role of practice in the development of performing musicians. *British Journal of Psychology, 87*(2), 287–309.
64. Gardner, H. (1998). *Extraordinary minds*. (pp. 149–152) New York: BasicBooks.
65. Cassidy, S. (2004). Learning styles: An overview of theories, models, and measures. *Educational Psychology, 24*(4), 419–444.
66. Cassidy, S., & Eachus, P. (2000). Learning style, academic belief systems, self-report student proficiency and academic achievement in higher education. *Educational Psychology, 20*(3), 307–322.
67. Krätzig, G. P., & Arbuthnott, K. D. (2006). Perceptual learning style and learning proficiency: A test of the hypothesis. *Journal of Educational Psychology, 98*(1), 238–246.
68. Coffield, F., Moseley, D., Hall, E., & Ecclestone, K. (2004). Learning styles and pedagogy in post-16 learning: a systematic and critical review Available from http://www.voced.edu.au/td/tnc_79.71 (Accessed March 23, 2009).

69. We argue with the notion that our cellular makeup predestines us to a style of learning, or even makes on easier than another. There are specialized cells; as we were finishing our writing, still another was discovered: Solstad, T., Boccara, C. N., Kropff, E., Moser, M.-B., & Moser, E. I. (2008). Representation of geometric borders in the entorhinal cortex. *Science, 322*(5909), 1865–1868. Most of the specialized cells feed into tissues that go on to store "memories" in the cortex. Not only is there compelling evidence for such cell types, but they most often are found when being specifically sought after their existence was predicted by a model – as in this recent report. There is a general storage geography for the brain. For example, visual content is stored at the back. Information from the left field of vision of each eye is stored on the right side. When one presses either the psychology or the biology, data supporting styles based upon genetic differences do not yet reveal themselves. Quite the opposite. Learning leads to development of "talents," and these talents appear to be reflected biologically in changes measureable with fMRI, etc. If there are style differences, they are small and most often readily overcome. As with any other difference, any inherent difference might be subject to a multiplier effect.
70. http://en.wikipedia.org/wiki/Homunculus (Accessed March 23, 2009).
71. Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. VIII, pp. 47–90). New York: Academic Press.
72. Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423.
73. http://en.wikipedia.org/wiki/Homunculus_argument (Accessed March 23, 2009).
74. Hazy, T. E., Frank, M. J., & O'Reilly, R. C. (2006). Banishing the homunculus: Making working memory work. *Neuroscience, 139*, 105–118.
75. Hyde, J., Lindberg, S., Linn, M., Ellis, A., & Williams, C. (2008). Diversity: Gender similarities characterize math performance. *Science, 321*(5888), 494.
76. With respect to gender differences, "the past 5–10 years have witnessed a surge of findings from animals and humans concerning sex influences on many areas of brain and behavior, including emotion, memory, vision, hearing, processing faces, pain perception, navigation, neurotransmitter levels, stress hormone action on the brain and disease states." (Cahll, L. (2006). Why sex matters for neuroscience. *Nature Reviews Neuroscience, 7*, 477–484.) Many of the gender differences reported are based in lateralizations; that is, something may tend to come in through structures on the left for men and right for women (or vice versa). One of the most obvious lateralizations one can observe is handedness. Some left-handed students require special equipment, such as student desks with writing tables on the left rather than right. As far as we know, there are no clear instructional strategies that differ based upon handedness. Does handedness matter? Well, think about this for a moment. About one in ten persons in the United States is left-handed. Of the last fourteen presidents of the United States, five have been left-handed and two others either left-handed or ambidextrous (http://en.wikipedia.org/wiki/List_of_left-handed_Presidents_of_the_ United_States (Accessed March 23, 2009)). The point is that, as with handedness, there may be something really important about instruction and gender that remains unknown to us. In *Brain Rules*, Medina devotes a chapter to gender differences. As we noted, many differences are related to lateralizations. Since no mention is made of handedness, and much of the writing is non-specific, we suspect that Medina is as unable as we are to nail down specific gender differences that might apply to learning. (Medina, J. (2008). *Brain rules: 12 principles for surviving and thriving at work, home, and school*. Seattle: Pear Press.).
77. Zeldin, A., Britner, S., & Pajares, F. (2008). A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *Journal of Research in Science Teaching, 48*(9), 1036–1058.
78. Geary, D., & Huffman, K. (2002). Brain and cognitive evolution: Forms of modularity and functions of mind. *Psychological Bulletin, 128*(5), 667–698.
79. Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.

80. http://en.wikipedia.org/wiki/Soar_(cognitive_architecture) (Accessed March 25, 2009).
81. Bereiter, C. (1990). Aspects of an educational learning theory. *Review of Educational Research, 60*(4), 603–624.
82. Ericsson, K., & Kintsch, W. (1995). Long-term working memory. *Psychological Review, 102*(2), 211–245.
83. Schraw, G., Brooks, D. W., & Crippen, K. J. (2005). Improving chemistry instruction using an interactive, compensatory model of learning. *Journal of Chemical Education, 82*(4), 637–640.
84. Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. VIII, pp. 47–90). New York: Academic Press.
85. Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423.
86. Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167–199; Simon, H. A. (1994). The bottleneck of attention: Connecting thought with motivation. In W. D. Spaulding (Ed.), *Integrative views of motivation, cognition, and emotion* (Vol. 41, pp. 1–21). Lincoln, NE: University of Nebraska Press.