Journal of Science Education and Technology, Vol. 15, No. 1, March 2006 (© 2006)
DOI: 10.1007/s10956-006-0353-0

Working Memory, Motivation, and Teacher-Initiated Learning

David W. Brooks[1,2] and Duane F. Shell[1]

Working memory is where we "think" as we learn. A notion that emerges as a synthesis from several threads in the research literatures of cognition, motivation, and connectionism is that motivation in learning is the process whereby working memory resource allocation is instigated and sustained. This paper reviews much literature on motivation and working memory, and concludes that the apparent novelty of the proposal offered to describe motivation in terms of working memory results from the apparent lack of cross-channel exchange among these research traditions. The relation between working memory and motivation is explored in the context of the interactive compensatory model of learning (ICML) in which learning is considered to result from the interaction of ability, motivation, and prior learning. The ICML is recast in light of the revised definition of motivation offered here. This paper goes on to suggest ways in which a range of teaching and learning issues and activities may be reconceptualized in the context of a model emphasizing a learner's working memory that makes use of chunks of previously acquired knowledge.

KEY WORDS: working memory; motivation; learning.

This paper posits that motivation is the process by which we consciously or unconsciously allocate working memory resources. That is, motivation is how we choose which of all of the memory chunks we have available to us we will activate—given that the number that can be activated is limited. This notion emerges as a synthesis from several threads in the research literatures of cognition, motivation, and connectionism.

MOTIVATION

Successful teachers are concerned with motivation and identify motivation as a key process in teaching. Pintrich and his collaborators (1994) recognized this and called for an integration of efforts:

> The purpose of this article is to explicitly integrate the motivational and cognitive domains of adolescent development and examine their interrelations in the classroom context of middle schools.

This work was not followed by a wave of interest or effort, however. The instructional design teaching literature is remarkably silent on the issue of motivation. The index of the 2001 (5th) edition of *The Systematic Design of Instruction* (Dick *et al.*, 2001) includes a few references to motivation, all of which point to the attention, relevance, confidence, satisfaction (ARCS) model of Keller (1987). None of these point toward learning systems intrinsic within a learner. The first ARCS step is to gain the attention of the learner. The other steps are ones that arguably are involved in both the first capture of attention as well as sustaining that attention. Similarly, the 2003 book *eLearning* (Clark and Mayer, 2003) makes one index reference to motivation which appears in an enumeration of problem-solving skills together with cognitive skills and metaskills and points to a reference by Mayer (1998). The index of *Designing Effective Instruction* (Morrison *et al.*, 2004) does not contain any explicit entries for motivation. There is

[1]College of Education and Human Sciences, University of Nebraska-Lincoln, Lincoln, Nebraska 68588-0355.
[2]To whom correspondence should be addressed; e-mail: dbrooks1@ unl.edu

some discussion of personal and social characteristics of learners, and the evaluation discussions include assessing learner "attitudes." In summary, the tools often used to teach instructional design pay little explicit attention to motivation.

It is likewise surprising that so little attention is apparently paid to cognitive studies of learning in the motivation literature. *The Handbook of Competence and Motivation* (Elliott and Dweck, 2005) is a case in point. The work consists of 35 articles and more than 5000 citations. The works of Baddeley and Hitch are never cited, nor is any work by Sweller. Older work of Mayer is cited once; Schraw is not cited. Schraw and Mayer are among the most frequent contemporary contributors to the educational psychology literature (Smith *et al.*, 2003). There are no citations to Norman (2004) who has written about *Emotional Design*. There are no citations to the work on neural modeling.

It seems apparent that these two large groups of researchers—the cognitivists and the motivationalists—are not making much use of one another's understandings and progress. It is not surprising, then, that an interpretation of motivation explicitly in terms of working memory has not appeared before.

The Reconceptualization of Motivation

Pintrich and Schunk (1996) define motivation as "the process by which goal-directed behavior is instigated and sustained." For learning to take place, a person needs to have working memory resources allocated to the learning task. An implied notion of motivation is that individuals have at least some control over whether or not to allocate these resources to learning (or any other task, for that matter). Therefore, the definition offered here is that *motivation is a process through which a learner consciously or subconsciously allocates working memory to a learning task.*

To a first approximation, working memory is the ability or capacity that limits how well one is able to undertake a learning task while motivation limits how much of that ability one is willing to apply to the task. Expressed as a sound-byte, *motivation deals with the willing portion of willing and able*. Much of the literature related to self-regulation openly speaks of "skill and will" (Paris and Cross, 1983). Garcia (1995) describes will as "students' motivational orientation in terms of goals, values, and expectancies." The self-regulation literature talks about what a learner is willing to give to a learning process, and much of this literature is aimed at teaching strategies intended to have learners take conscious control of their effort. The claim made here is that what needs to be willed on the part of the student amounts to an appropriate allocation of working memory.

This is more than a simplistic change in wording. It allows for a systematic review of the recent contributions from three literatures (cognition, motivation, connectionism) in the context of a single widely accepted model, that of working memory (Andrade, 2001).

WORKING MEMORY

Miller introduced the notion of limits to the amount of long term memory that a person might be able to use effectively at a given instant (Miller, 1956). This led to the emergence of a model called working memory (Baddeley and Hitch, 1974). For the purpose of this paper, we make three points about working memory:

- working memory is "where" cognition happens,
- the capacity of working memory is limited, and
- that capacity is affected by prior knowledge which allows chunking.

Working Memory Models

Working memory concerns that part of the memory system dealing with the temporary storage and manipulation of thoughts during cognitive processes. The principal focus in this paper is upon school-based learning; however, working memory is used for processing in all other situations (athletic, work, everyday living). Working memory imposes limits upon access to long term memory (Baddeley, 1992). Recently, eleven different models for working memory were described (Miyake and Shah, 1999). The best known and most widely cited model of working memory envisions three components: an entity for visual information; an entity for aural information; and a controlling or central executive entity (Baddeley, 1986; Baddeley and Logie, 1999). More recently, Baddeley has argued for the addition of a fourth episodic component (Baddeley, 2000).

Working memory may be better described in terms of a process than in terms of a place. An attractive alternative model to that of the visual/echoic/executive also involves three components: long term memory, the currently activated subset of long term memory, and that subset of activated memory that is in the focus of awareness and attention (Cowan, 1999). Engle *et al.* (1999) have elaborated on that model:

> . . .but individual differences in capacity for controlled processing are general and possibly the mechanism for general fluid intelligence. Although people can, with practice and expertise, circumvent the abiding limitations of controlled attention in quite specific situations, the limitations reemerge in novel situations and even in the domain of expertise if the situation calls for controlled processing.

Working Memory Capacity

Working memory capacity can be measured in any of several ways. When digits (numbers) are read aloud to a person at a rate of one digit per second, that person usually is able to recall about seven digits. In this paper we are using a measurement—such as the number of digits recalled after hearing them read at a rate of one-per-second in the absence of using a recall strategy—to describe working memory capacity. Most people can develop a strategy to raise their recall to about 20 digits. One person actually raised his skill to a level of recalling 82 digits (Ericsson *et al.*, 1980). It took him two years and 264 sessions to attain this skill level even though his starting level was not atypically high. In the model we present here, we describe this skill change in terms of the person's strategy for chunking the incoming information.

Humans of ordinary ability are able to develop very significant levels of skill through deliberate practice (Ericsson, 1996; Ericsson *et al.*, 1993). While deliberate practice has several well-defined characteristics, it is clear many persons of exceptional skill began with no evidence of special "gifts."

Working memory is not some constant intrinsic characteristic of a learner. Its function at a given instant depends upon content and context, and it is very dependent upon a learner's prior experience. Humans *chunk* content pieces together such that very large amounts of content are concurrently made accessible. In fact, Simon (1974) argued on behalf of a strategy for measuring chunk size. Experts, those with deep and specialized competence, make use of big chunks that were developed over those years during which they became experts. These chunks continue to develop while they work as experts.

Experimental work from Engle's group suggests that working memory capacity reflects "the ability to engage controlled attention" (Kane *et al.*, 2001). In later work, it is asserted that "there is a large and consistent body of research to indicate that the capability to control attention (especially in contexts in which there are competing demands) is a major determiner of an individual's performance on complex working memory tasks" (Feldman Barrett *et al.*, 2004).

Ability, Fluid *g*, and Crystallized *g*

Ability often is intertwined with the term intelligence and has led to substantial controversy. It is not surprising that, after an introduction, the first topic addressed in the *Handbook of Competence and Motivation* is intelligence (Sternberg, 2005). Sternberg stresses compensation in this article. Ability does seem to be changeable within certain contexts To account for the observation, researchers have divided their consideration of the construct of intelligence into two parts: crystallized intelligence that can be changed though experience, and fluid intelligence that is a less mutable entity (Jensen, 1992).

It is worth noting that Sternberg cites changes in fluid ability over the twentieth century to suggest that "the notion of fluid abilities as some basic genetic potential one brings in to the world, whose development is expressed in crystallized abilities, does not work" (Sternberg, 2005). It remains that the variance within populations remains quite large as compared to the time-based changes that have been observed. Johnson (2005) very recently explored possible reasons related to the complexity of games and of some other forms of entertainment that might account for these changes. Not only can actual ability be divided into fluid and static components, but Dweck and Leggett (1988) have also found that person's perceptions of intelligence also correspond to an entity (fixed) and an incremental (plastic) dichotomy.

Because this paper seeks to link notions from different research traditions, the recent publication of the *Handbook of Competence and Motivation* (Elliott and Dweck, 2005) is noteworthy. Competence is defined as 'a condition or quality of effectiveness, ability, sufficiency, or success.' The notion of ability used in the present article deals with an entity that enables competence rather than as an outcome of achieving competence. Competence motivation broadly takes into account most aspects of human life. The present work focuses on reasonably advanced learners (high school or older, and possibly middle school/junior high school) and tasks connected to what is conventionally thought of in terms of school learning or material that could be taught in school (chemistry, real estate, completing tax forms).

Cognitive scientists are appreciating the notion that cognition is a dynamic feature of people, and that the amount of cognitive skill one is able to bring to a problem depends upon contextual circumstances often described using words like emotion (Dai and Sternberg, 2004). Ellis and Ashbrook (1988) have described an allocation model for this phenomenon. The model accounts for decreased memory performances of depressed versus normal subjects. Ellis connects this model to earlier work suggesting that attention is a limited resource. Recent research along these same lines suggests that *both* positive and negative emotions compete for resources (Meinhardt and Pekrun, 2003). Beilock and Carr (2005) describe an experiment in which the pressure-induced performance of "high-powered people" is diminished. They attribute the outcome to the pressure having occupied some working memory capacity.

Fluid *g* and Working Memory

Is there a relationship between fluid *g* as described by intelligence workers and working memory? Engle and his collaborators (1999) have reported strong correlations between these two constructs. A recent but very dramatic claim for a connection between fluid g and working memory comes from Colom *et al.* (2004). The title of their paper, "Working memory is (almost) perfectly predicted by *g*," encapsulates this claim.

In situations where learners have little or no prior experience, working memory probably is an intellectual feature that can be measured by a variety of tests. When pushed onto unfamiliar ground, working memory is limited and sets boundaries upon what can be quickly accomplished. Nearly all humans are well described in terms of having such a limit. In familiar settings, however, our success depends upon prior learning and experience. The expert has skills that are chunked (incorporated into long-term memory) such that extremely powerful problem solving becomes apparent.

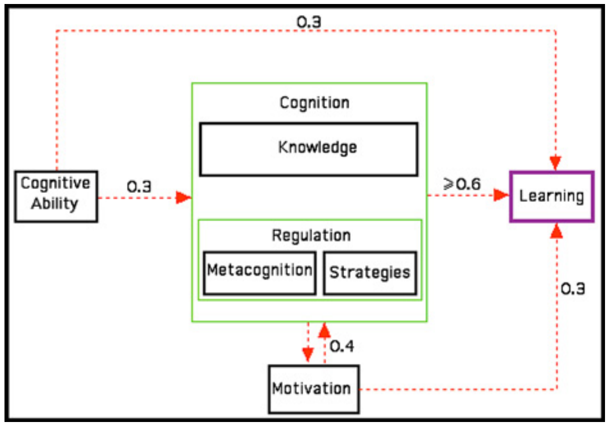

Fig. 1. Schematic of the Interactive Compensatory Model of Learning (ICML). The numbers are estimated correlation coefficients. Source: Schraw *et al.* (2005).

THE INTERACTIVE COMPENSATORY MODEL OF LEARNING (ICML)

How might the proposed notion interpreting motivation in terms of the allocation of working memory affect the way in which educators view the motivation construct? We provide one illustration using a model recently proposed by Schraw, the Interactive Compensatory Model of Learning (ICML), that integrates motivational and cognitive influences on learning as depicted in Fig. 1 (Schraw *et al.*, 2005).

The numbers written as correlations in Fig. 1 represent approximations based upon Schraw's extensive review of the literature regarding the relative contributions of prior knowledge, ability, and motivation toward the success of new learning. A key feature of this model is that prior knowledge accounts for at least 36% of the variance when considering subsequent performance. Douchy *et al.* (1999) support this. Shaprio (2004) suggests that, in spite of the emphasis placed upon estimating prior knowledge, its contribution still often is underestimated. A key notion expressed by Schraw and reflected in the ICML name is that, for the most part, people can compensate for and overcome weaknesses to become successful learners.

Revising the ICML

The history leading up to the present paper really began with the instantiation of Schraw's ICML that, though published only recently, was developed

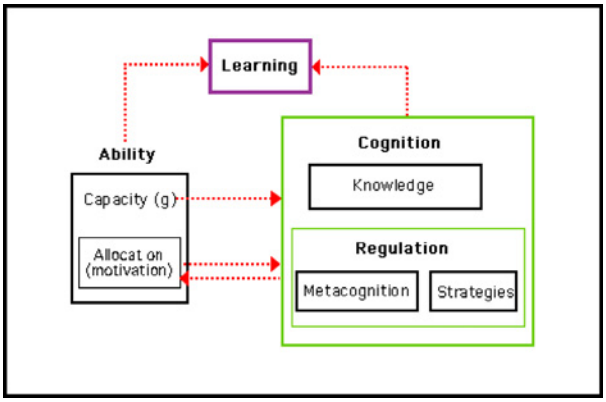

Fig. 2. Modified ICML in which ability and motivation are merged.

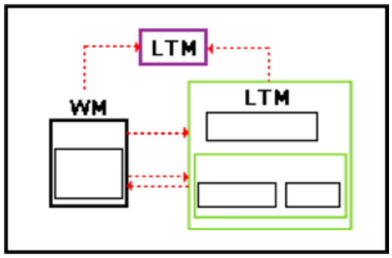

Fig. 3. Revised ICML as related to neural function. In this model, new learning (*top*) will become stored in long-term memory. Prior learning also has been stored in long-term memory. New learning ultimately becomes available to inform later learning. While working memory has access to activated long-term memory, the role of working memory is both temporal and capacity limited.

a decade ago. The model proposed here would involve merging the boxes for ability and motivation of the ICML described in Fig. 1 into a single box as in Fig. 2.

The notion of the revised model is as follows. A learner has a limited working memory capacity into which potentially appropriate chunks may be loaded. Depending upon experience, each chunk's size (it's power, it's capability) may vary enormously.

Some allocation is subconscious, but the learner also has at least some conscious control over how much of the available resource is allocated to a task. The learner does not know explicitly the number of chunks that can be mobilized in a task. That is, the learner cannot say to him- or herself, "I can use up to six chunks so I'll load this one and this one and . . ." Prior experience almost always gives the individual learner a personal sense of how much "effort" is possible and how much "effort" is needed, however.

In this revised ICML, learning is envisioned as a process of long-term memory mediated by working memory. The ICML paper referred to working memory only once (in connection with ability) and long term memory twice (each time identifying it as the site of the knowledge base). Figure 3 illustrates how these aspects of the model might be emphasized.

In this model, the rate of learning ultimately is ability limited. However, prior learning and prior experience affect new learning. In the model, motivation places an important boundary on learning. Motivation determines how much of what a learner has got to work with on a problem actually is applied to that problem. The absolute capacity is largely fixed by ability; the effective capacity is set by motivation. Nothing in our modification of the ICML changes its main message: effort pays.

ABILITY–MOTIVATION INTERACTION

There are two extremes or poles from which one might view the ability-motivation interaction. At one pole sits the expert where, as a result of chunking, knowledge and expertise are high (the crystallized ability is large) and motivation tends to be top–down. Experts exhibit total involvement—flow. A virtuous cycle becomes established. Motivation is largely unconscious, automatic, and built-in.

At the other pole sits the novice where knowledge and expertise are low (that is, where crystallized ability is low). Attention tends to wander. Strategies such as forethought and reflection probably need to be employed to sustain motivation. Regulation of motivation becomes an issue. Much of motivation is conscious, explicit, and consumptive of at least some working memory potentially available for something else. In the next two "sections" of this paper we develop some contrasts between experts and novices relative to working memory utilization.

Expert Thinking

Full Capacity (Flow; the Zone)

A teacher learning about working memory might immediately jump to the conclusion that they should fully engage students' working memories in a single focused activity. Indeed, this happens often; people engage in time-consuming and challenging activities under circumstances where external rewards do not seem to be involved. Csikszentmihalyi *et al.* (2005) describe flow as "a subjective state that people report when they are completely involved in something to the point of forgetting time, fatigue, and everything else but the activity itself." Others describe this state in terms of "the zone."

> The zone is a mental state which includes a sense of calmness and confidence. Actions and decisions are effortless and easy. There is no self-criticism and the person is living in the moment. The athlete is playing in the here and now (Granat, 2005).

Many have noted total involvement with effortful tasks such as studying or writing a paper or reading the literature. Musicians and actors and athletes similarly report times of total involvement. As noted, athletes have come to refer to this status as being "in the zone."

When studied during such times, students often report that nothing else other than the task makes it through to conscious attention (Reed *et al.*, 1996). Indeed, it is one of the more unusual characteristics of fully self-regulated learners that, when they are fully involved in an effortful task, there is no apparent evidence of self-regulation (Reed *et al.*, 2002). There is no positive self-talk or wrestling over next steps or self-explanation or the like. Instead, there is essentially fully automated, continuous activity.

We suspect that being "in the zone" is not rare. A 12-month-old props herself to a standing position and, for the first time ever, steps quickly to grasp the outreached arms of a parent 6 ft away. For a few moments, she was "in the zone." A colleague who looks quite bedraggled early one morning allows that he started reading a book the preceding night and "just couldn't put it down." For several hours, he likely was "in the zone." Flow is an enjoyable state; once achieved, it is likely to be repeated. The characteristic of experiencing flow, of working the zone, is that working memory is fully occupied. There is no need to prod the process along with self-talk or questioning. For most of our lives, however, we are not in the zone. We are questioning ourselves; we are rather easily distracted.

A Virtuous Cycle

When adults flow in the zone, there is no necessary explicit motivation other than self-efficacy or competence motivation. Whatever early processing is done on inputs from sensory buffers, that processing alone is sufficient to "select, orient, and energize behavior" (McClelland, 1987). In many teaching-learning situations, what the teacher needs is already in place in the learner. In fact, this is true so often that those texts dealing with systematic instructional design noted earlier can be useful while paying essentially no explicit attention to motivation. Bandura (1991) speaks of successful learning leading to enhanced self-efficacy that leads to more successful learning—in an unending virtuous cycle. In other words, once successful learning gets started, it doesn't necessarily need much or even any "help."

Novice Thinking

Most of the persons reading this article are probably more concerned with novice learners than expert learners. Novices may struggle to learn. To sustain this struggle, some positive self-talk may be needed and, in order to generate that self-talk, some working memory must be applied. Later we will point to evidence that, in order for teacher-directed learning to take place, at least some working memory resources must be set aside for the teaching.

Cognitive Load

The large and growing literature dealing with "cognitive load" helps focus on issues of what amount to novice learners. The notion of connecting capacity to the design of instructional materials was introduced by Sweller in the late 1970s, and more than two decades of effort have been devoted to these studies (Sweller *et al.*, 1998). Cooper (1998), a colleague of Sweller's, does not take sides relative to models for working memory. He uses very general definitions:

- "Working memory is the part of the mind that provides our consciousness. It is the vehicle which enables one to think (both logically and creatively), to solve problems and to be expressive."
- "Cognitive load refers to the total amount of mental activity imposed on working memory at an instance in time."

Mayer and his collaborators have focused on multimedia learning (Clark and Mayer, 2003; Mayer, 2001). Sweller's and Mayer's efforts have been remarkably parallel. Indeed, Mayer and Moreno (2003) set forth a systematic comparison of the efforts and outcomes from both Mayer's and Sweller's prolific research groups. Other researchers have engaged in important related efforts (Renkl and Atkinson, 2003; van Merrienboer and Krammer, 1990).

When engaged in a learning task, the learner must utilize some working memory capacity, and hence a load is placed upon that memory. Instruction places at least two kinds of demands upon the learner: those demands inherent in the learning (*intrinsic* load), and those demands resulting from instructional design (*extrinsic* load).

The impact which Sweller's thinking is beginning to have upon contemporary instructional design often is underestimated. One entire issue of the *Educational Psychologist* was devoted to work related to cognitive load (Paas *et al.*, 2003). There are numerous studies one can cite from the literature through which learning can be enhanced by choosing strategies that lower cognitive load. Goal free problems in which the learner is asked to tell as much as she/he knows or can figure out in a problem is one (Ayres, 1993; Owen and Sweller, 1985). Another would be the use of worked out examples (Cooper and Sweller, 1987; Paas, 1992; Paas and van Merrienboer, 1994; van Merrienboer and Krammer, 1987; Zhu and Simon, 1987). Instructional design is now at the level of determining the most appropriate way to accomplish the sequential fading of steps when teaching using worked examples (for example, see Renkl *et al.*, 2004).

At the same time that specific instructional design issues have been raised through the efforts of Sweller, Mayer, and others, a large number of general references positing relations between learning difficulty and working memory load have appeared. In chemistry education, for example, Johnstone (1991) was among the first to make use of this concept. Johnstone discussed problems typical of introductory chemistry courses in terms of how many chunks he determined that a learner would need to manage at once to successfully solve the problem. After the emergence of handheld calculators as tools in introductory college chemistry courses, the number of chunks required in typical end-of-chapter problems increased markedly.

It also is important to rethink the cognitive load research in these terms. If one connects cognitive load to working memory and working memory to fluid *g*, then one can argue that the last three decades of work in instructional design have amounted to discovering systematic ways to lower the fluid ability needed to achieve learning success with a set of learning materials. When the term ability is used, one might suspect that lowering load amounts to "dumbing down." To label the cognitive load research in this way is inappropriate. There has been an important effort to minimize the load artificially imposed through instructional design without changing the underlying learning goals whatsoever.

Teachers, Deliberate Practice, and Germane Load

The process of learning is one that proceeds from raw beginnings (small cerebral chunks) up to a level of high expertise (large cerebral chunks). In attempting to achieve expertise, Ericsson *et al.* (1993) posit that one must engage in deliberate practice, an activity that involves overt, conscious self-regulation. So, when a person is "in the zone" (fully involved), there can be essentially no learning about the automated process being undertaken. Ericsson stresses the need for deliberate practice as distinct from total performance.

Teachers cannot successfully teach learners who are experiencing flow. It needs to be appreciated that to teach, to bring about deliberate practice, requires that some working memory space be allocated to the teacher and/or the teaching. Teachers usually want learners to become experts and to help them engage in deliberate practice as needed and appropriate. That is, teachers would like their students to experience the zone in course content areas. It is not widely appreciated that, while in the zone, the learner is out of reach. Winne (1995) has addressed this problem explicitly:

> Monitoring levies charges against a learner's limited attentional resources (or working memory capacity). In the midst of a task, overly frequent monitoring or monitoring against a vague or too long list of criteria, may put students in a deficit position. It can obstruct access to cognitive resources they should apply toward acquiring the subject they are studying by assembling new information with prior knowledge, translating information across representational forms, and rehearsing information (see Winne, 1985, 1989).

It may be that these ideas have been expressed equivalently using the notion of germane load. In some learning situations, learners need to think rather deeply about a problem. Renkl and Atkinson (2003) claim "different learner activities during the later stages constitute either germane or extraneous load, because different instructional goals are to be achieved." The specific example cited by Renkl and Atkinson is that of generating self-explanations, a self-regulatory strategy often used when solving science, mathematics, and engineering problems (for example, see Chi *et al.*, 1994). They go on to propose worked examples in which worked portions are faded in favor of learner-supplied intermediate responses. That is, you show a worked problem. Then, in the next problem, you require the learner to provide problem components and so on in an ever-increasing manner ending with the learner solving an entire problem.

The model proposed here accounts for these observations. Some of the learner's allocated working memory must be assigned to the process of learning. As noted earlier, learners are not likely to learn under a full load where they experience flow and have not allocated those chunks with which we tear things apart intellectually.

Development

When considering novices, some attention should be paid to development. That is, how do novices become experts? Any complete learning model should account for the stages frequently referred to in Piagetian descriptions of learning (concrete, formal, etc.) Cognitive development can be viewed in terms of neurological changes (Quinlan, 2003). One general approach to understanding cognition in terms of neural change is called connectionism. An exciting view of development is expressed in the seminal connectionist book by Elman *et al.* (1996) *Rethinking Innateness*. While a single, comprehensive, connectionist model for learning and development is not at hand, it may be on the way (Spencer and McClelland, 2005).

Connectionist notions may be applied to the model of a chunk discussed earlier. What does it mean to chunk? There is an intuitive temptation to think of chunking as adding one process to the end of another such that big chunks will be made up from little chunks somehow connected end-to-end. The output, then, would be more processed. In fact, serially connected little chunks forming a big chunk is a poor model of a neural network. Instead, the neurons behave more like a hologram with numerous interconnections between neurons. Collections of neurons seem to behave as if they are in planes or layers of connections.

Development can be modeled in terms of adding layers (in the computer science, neural network sense of that term) to a processing sequence. Extant, functioning neurons take on more "responsibility" as new "layers" are constructed. There are numerous types of neuronal tissue in the human brain, and the specializations are varied and important. However, the tissue in the cortex seems to be there to "remember." Although humans typically have cortical regions divided up to support particular tasks (to recall vision, to recall how the arm works), these regions are not that different from one another. Tissues in the cortex can be repurposed, and they often are after some accident or disease process (Merzenich *et al.*, 2004). In fact, humans can develop new neurons after birth (Eriksson *et al.*, 1998).

As we learn and grow intellectually through deliberate practice and experience, the tissues in our cortices become better and better at processing tasks. We've used the term *chunking* to describe the observable performance outcomes that result from what actually is a biological process, one that actually involves molecules and tissues. We speak (inappropriately) of chunks becoming larger and larger. It probably is both incorrect and limiting to think of chunks in terms of physical adjacency within tissue masses. It might be closer to the physical reality if we would speak of the chunks as developing more and more internal layers.

Development occurs through learning and experiencing such that the chunks we are able to call into action while learning become potentially ever more powerful. Connecting this back to the overall model, the number of such chunks that we can keep activated (keep track of) is small, perhaps seven or less, and the number we can focus upon at any given instant is probably just one.

For the infant taking several first steps to reach her mother's outstretched arms, it may take all of her available capacity (which may be more or less than seven chunks) with numerous separate chunks becoming involved. In adulthood, that same person will be able to perform that walking task automatically using many fewer chunks. This is what leads to observable changes that we lump together when we speak of stages of development such as concrete operational and formal operational stages. As chunks grow more powerful such that we need fewer slots to accomplish tasks, we can activate other chunks while still being successful at a task that once was all consuming of resources.

This paper posits that motivation is the process by which we consciously or unconsciously allocate working memory resources. That is, motivation is how we choose which of all of the chunks we have available to us we will activate—given that the number that can be activated is limited.

Chaos

Another issue concerns how things become chunked together. In teacher directed learning, the teacher can use one slot (or chunk) with which to have the learner light up two other chunks and begin the process of bringing them together (connecting them). Learning does take place without teachers, however, and the mechanism of processes whereby we figure out things for ourselves must fit into a learning model. A reality of life is that many brain events are (seemingly) random. Some neurons fire, and the result is an experience, a perception, a thought, or perhaps even a mental image. Freeman (1999) models the process of brain function in his book, *How Brains Make Up Their Minds*. The term chaos often is mistaken to mean random. In fact, chaotic functions are bounded in the sense that solutions to equations are found within an envelope of accepted solutions and not just any old place.

Freeman claims:

> Yet unpredictability is inherent in chaotic trajectories, and introduces flexibility and creativity in the construction with each new state transition. Chaos generates the disorder needed for creating new trials and trial-and-error learning, and for creating new basins in assimilating new stimuli. Its high-frequency oscillations maximize the likelihood of firing coincidences, which are required during the process of Hebbian learning. As a result, brains are drenched in chaos. It gives an optimal balance between flexibility and stability, adaptiveness and dependability.

A chaotic mechanism underpins at least some chunking. Indeed, some pleasant thoughts are encouraged and occur over and over. Some demonic bad thoughts just don't go away easily, and pop up often as in nightmares.

A consequence of this chaotic mechanism is that working memories have an opportunity to manipulate two or more thoughts that may not have had prior connections. This is a mechanistic model for creativity. One can think of two chunks not formerly thought of as being connected that pop into working memory together and, once there, end up being connected.

A quotation often attributed to the famous scientist Louis Pasteur is that "chance favors the prepared mind." Here chance is not generally thought of as meaning firing of a neural chunk but finding oneself in the midst of some unexpected world event. The bigger ones extant chunks, the more likely meaningful patterns will be detected and appreciated by the learner confronted with the unexpected event.

TEACHING; INSTRUCTIONAL DESIGN STRATEGIES

This paper may seem like a simple word transformation with no obvious gain for the teacher. Consider the following analogy. In mathematics, we usually learn first about rectangular coordinate systems wherein a point relative to an origin is specified by x, y, and z coordinates. *Any* problem that we might wish to solve can be solved in the context of such a coordinate system. A different coordinate system also can be used to specify points relative to that same origin. Whatever problem is expressed in xyz coordinate terms may also be expressed using spherical coordinates (r, θ, and φ). A transformation of coordinates makes some problem situations more easily visualized. It's not that the problem has changed; it's that the redescription makes different alternative approaches to solving the problem simpler to envision, describe, and achieve.

This paper is redescribing motivation in terms of the mental process that a teacher must affect within a student before teacher-initiated learning has a chance to take place. The way a teacher might come to view teaching in terms of the reconceptualization advocated in this paper is in terms of capturing sufficient working memory resources from each learner to support learning. Each learner's motivation determines how much of the available resources will be assigned to the learning activity. This paper also stresses that, for a learner, some working memory must be allocated to those tools that will lead to learning—self-regulatory tools, if you will. As discussed by Winne (1995), this allocation may be problematic for learning, especially in novices.

Focusing on the Cortex (Top Down)

The learning model we are advocating is one in which the cerebral cortex stores information which is called upon through working memory. Prior learning (i.e., cortex-based storage) makes the biggest contribution to successful new learning.

While much information may be stored, the working memory limits the amount that can be brought to bear on a problem at a given moment. The motivation, that property of the system that keeps us working and trying and putting forth effort becomes a fully integrated part of this system. Campbell and Bickhard (1986) incorporate such a notion in their development model, for example. In the preface to his book, Zimbardo (1969) writes "We believe that some of the appeal of our work . . . lies in its empirical demonstration of the extent to which, and the specification of the conditions under which, man can control the demands imposed by his biological drives and social motives."

When dealing with adult learners who have achieved reasonable levels of competence, the processes that lead to resource allocation are built into the cortical structures. That is, chunks stored in cortical structures can utilize all "slots" in the working memory. There is no special need to attend to motivation; the act of full working memory involvement will be part of a virtuous cycle, and the outcomes from the processing will increase or decrease the likelihood of subsequent full allocation.

An expert who is fully self-regulating in a particular content domain may spend much time totally involved (Reed *et al.*, 1996, 2002). At these times, actions are running in automatic mode, and there is no perceptible reflection until one works up to some kind of stopping point. So, the expert works along in a determined way and reaches a stopping point or a point where the monitoring system decides that the task is complete or that something is not quite right. At those times, expert self-talk pops in.

For the novice, this is not the case. For the novice, little may be automatic. There may be much self-talk, and possibly even self-doubt expressed in the novice's own voice. Earlier we noted that most people can estimate how much effort a task will require. Some tasks have attributes that cause a potential learner to immediately say something like, "Oh, that's math. I can't do math." These are the times when the teacher or instructional designer needs to be able to access as much of the learner's resources (working memory) as possible.

In a most general sense, then, *the role of the successful teacher is to build up those chunks that a learner uses when things are not going well*. These are the tools best automated and emphasized—building what amount to powerful, self-regulatory units that can be used in working memory without taking up all of that memory space. The motivational process in the learners should be one wherein they turn to such chunks when things are not going well.

Don't underestimate the potential for the simple strategy of asking for attention. Anyone who has visited classrooms often has heard teachers ask students to "pay attention," often when starting a new topic or after some admonition related to undesired behavior such as "John, quit talking to Sally, turn around, and pay attention."

Mastery

Mastery learning has a very good history as a teaching strategy (Bloom, 1976, 1984). This strategy has been advocated for decades (Brooks *et al.*, 2003; Moore *et al.*, 1977), especially now when multimedia delivery systems support facile implementation of systems for unlimited learning practice. Mastery certainly is consistent with the ICML (Schraw *et al.*, 2005) and with the importance of prior knowledge (Shapiro, 2004). As teaching systems are developed for novice learners, explicit motivational content for mastery addressing the forethought and self-reflection phases of developing self-regulatory behaviors can be included. It is hard to imagine an outcome more likely to affect self-efficacy than that of achieving content mastery (competence) in a subject.

One of the greatest challenges facing teachers is the apparent tension between effort and ability. While young children view effort and ability as complementary, older children see them in conflict (Nicolls, 1984). An observation that emerges time and again and in study after study is that effort pays off. At the same time, rewarding effort rather than outcome may not be fruitful (Schunk, 1983, 1991).

Strategy Instruction

Weinstein and Mayer (1986) wrote a classic chapter on learning strategy instruction in which they elaborate strategies. This chapter included one early sentence about positive self-talk and less than one page on "affective strategies," with nearly all of that material focused on performance anxiety. Hadwin and Winne (1996) review strategy skills used in higher education and conclude that support is "meager." When strategies are taught in courses focusing just on strategy, transfer from the study courses to other courses seems to be poor. Three strategies are identified as having positive effects on achievement: concept mapping, self-questioning, and monitoring one's time spent in courses. Their paper focused on ecological uses of strategies. Winne is careful to use studies relating only to college students, and excludes those from students at lower than college grade levels.

A stand-alone course on strategy instruction found higher graduation rates for its alumni in spite of lower SAT scores (Weinstein *et al.*, 1997). Generally speaking, results from strategy instruction either within courses or from generic courses have been mixed. The best results seem to obtain when the strategy instruction is explicit and offered within the context of a course.

Teacher's offering strategy instruction should keep in mind the notion that memory allocation needs to be monitored. When the learner is not allocating sufficient working memory, that's probably a motivation issue.

Regulation of Motivation

Among the many ways one might expect to help learners become successful through self-regulation, it is surprising that the regulation of motivation has received little attention. Wolters (2003) addressed this issue explicitly. He asserts: "regulation of motivation concerns only the thoughts and actions through which students deliberately try to influence their motivation regarding a particular activity." He continues to describe a series of strategies for regulating motivation: self-provided consequences for behavior; goal-oriented self-talk; interest enhancement; structuring the environment; managing efficacy; efficacy self-talk; subdividing tasks into smaller chunks; attributional control (it's up to me, not someone else); and defensive pessimism. There also are some strategies of questionable merit. In self-handicapping, students create barriers to success such as putting off to the last minute. In defensive pessimism, students stress their unpreparedness in ways likely to decrease the effort they expend on learning.

Attention to Forethought and Reflection

In their recent work on regulating intellectual processes and outcomes, Zimmerman and Schunk (2004) describe a "cyclic phase model of academic self-regulation" consisting of a forethought phase, a performance phase, and a self-reflection phase. Generally speaking, more emphasis is placed the performance phase with little instructional effort spent on the forethought or reflective phases.

An instructor's goal in these phases of instruction can be recast in terms of working memory allocation. During forethought, the teacher needs to set the stage for having students allocate sufficient working memory during the performance phase. During reflection, the teacher needs to increase the likelihood that sufficient resources will be allocated on subsequent occasions when the material is encountered.

Within the overall admonition to not waste time (Zielinski *et al.*, 2001), it likely is important to include reflective materials during and after instruction. One goal of this phase can be to ascertain whether the learner had allocated adequate working memory to the learning task. Another might be to help store the newly learned material with the kinds of connectors likely to help use of resources. That is, try to make the new learning "light up" when it is likely to be needed later.

Content Details

It is hard to overemphasize that designers can overdo efforts at motivation and end up wasting students' time (Zielinski *et al.*, 2001). Motivation is the process through which learners allocate resources, and the designer's goal is to develop instruction that garners those resources. One area that is very problematic for many science and mathematics teachers is the inclusion of content details to stimulate interest. The literature has come to call such materials seductive details (Schraw and Lehman, 2001). Attention to them requires allocation of working memory and, as such, may reduce allocable resources. On the one hand, these details often get in the way of new learning. On the other, they sometimes become pegs around which learners develop personal interests from a milieu of situational interests (such as the arrays of factoids provided by teachers). Schraw and Lehman (2001) suggest that, in some circumstances, details that enhance learning might better be described as supportive details.

Inquiry

Inquiry is a troubling strategy. On the one hand, what better way to become a scientist than to role-play as a scientist confronting the same kinds of issues scientists confront every day? That notion has face validity, and certainly is consonant with supervising undergraduate and graduate students in the preparation of theses.

There is another side to this. One of the most advocated if not most popular teaching strategies of the past three or four decades has been discovery. Discovery is used very often in science instruction.

Generally speaking, and especially when the learners are inexperienced, the cognitive load associated with discovery is much greater than that of, say, worked examples (Tuovinen and Sweller, 1999). Several methods of instruction have been reviewed, and poorer outcomes related to discovery appear rather general (Taconis *et al.*, 2001). Klahr and Nigam (2004) compare direct and discovery methods in early science learning, and find that "many more children learned from direct instruction than from discovery learning, but also that when asked to make broader, richer scientific judgments the (many) children who learned about experimental design from direct instruction performed as well as those (few) children who discovered the method on their own."

Data suggest that the cognitive load is greater in discovery than direct instruction (such as worked examples). In terms of the working memory model favored here, it is not clear which prior learning (in long-term memory) needs to become activated during a discovery activity. Indeed, it is not clear at the outset of some discovery strategy activities whether information needed to solve a problem already is part of the learner's knowledge base; very often, deciding what you know and what you need to get to know is a part of a discovery activity.

For the most part, discovery has not been investigated from the perspective of motivation. That is, while engaged in discovery, how much of their available working memory resources are the learners devoting to the learning task? Discovery learning generally is perceived to be more engaging. In other words, learners probably are allocating more attentive focus during discovery-based activities than other activities such as worked-out examples.

The time has come to revisit several highly advocated teaching strategies (discovery, cooperative learning) from a twofold perspective. On the one hand, cognitive loads need to be compared. However, having activities with reduced loads that students choose not to allocate resources for is just as unproductive as getting full attention for tasks too big for effective learning. By viewing motivation from the perspective of resource allocation, a more formal tool may emerge for assessing instructional strategies beyond "they liked it" or "they didn't."

SUMMARY

The intent of this paper has been to advocate a revised conceptualization of motivation in learning in terms of the concepts of working memory, long term memory, and chunks. Learners are seen as having a more or less fixed ability often expressed either as fluid *g* or working memory capacity. Fluid *g* and working memory capacity are seen as essentially identical concepts or, at the least, hugely overlapping ones. Working memory is dynamically loaded with chunks, and chunks may be of dramatically different ability (competence, potential, or "size"). Chunk growth, taken to be the same as increasing crystallized intelligence, is the principal mechanism for acquiring expertise. Motivation, also seen as neurologically stored, may occupy chunk spaces within working memory. In experts, motivation has become included in their (massive) processing chunks. Early processing from sensory inputs lights up the needed chunks, and there is little if any allocation to explicit motivation. Novices operate quite differently. Often struggling to make sense of inputs much less process them, novices may need to allocate resources to positive self-talk or other so-called motivational strategies that, while wasteful of potential resources on the one hand enable sustained further effort on the other. The article ends by suggesting a variety of teaching and learning contexts in which the revised motivation model might be viewed.

ACKNOWLEDGMENTS

Numerous colleagues and students have contributed to this work through responses to early drafts and by providing awareness of other work. We are especially grateful also for the contributions of Robert Calfee, Kent Crippen, David Fowler, Nanette Hogg, Daonian Liu, David Moshman, Gayle Nicoll, Doug Phelps, Allen Steckelberg, Guy Trainin, and Kathleen Wilson.

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