Chapter 11
A Focus on Thinking

Check in the index of a book on cognitive psychology or instructional design and you're not likely to find an entry for "think."[1] Ask a college science teacher what their goals for students include and you almost always hear "teaching them how to think." Look up "thinking" in *Wikipedia* and you find ". . . allows beings to model the world and to deal with it effectively according to their objectives, plans, ends and desires." Your dictionary will likely express several different definitions, all of which you'll have heard and be able to relate to.

What is thinking in the ULM? We have alluded to critical thinking and problem solving in Chapter 4 as continued search in working memory for new sensory input (new information) and restructuring and transforming available sensory input into different configurations for the purpose of creating a pattern match. We want thinking of this sort in our classroom when we want students to use what they have learned to solve problems or answer questions. We would like them to be able to "think" about their answers beyond simple rote regurgitation.

We also want students to think about what they are learning. Thinking in this context means something a little different. It means making sense of what they are learning. Students need to build their knowledge by transforming it and connecting it to existing knowledge. Creating pattern matches that retrieve prior knowledge to help understand what is being learned and place it in context.

Thinking involves working memory. As we learn new things, the intrinsic load of the new material may be such that we can't do too much beyond the simplest processing with what currently is active in working memory. While we can successfully learn how to do what we need to do at the moment, we don't really get the chance to see why we are doing it or how what we are doing fits in with other things that we know.[2]

Keep in mind three things about encouraging thinking: learning requires repetition, learning is about connections, and learning can either be effortless or require effort. At the end of a lesson, it is very reasonable to review what has been covered and to connect that new learning to other things as described in several examples we have already mentioned. This fits well the rules of repetition and connection. The context often is a casual one, and thus this learning is stored in episodic memory;

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it is effortless learning. If the learning is not emphasized in some way, it is subject to the vagaries of episodic memory. Effort is almost certain to be required to help move this from episodic to semantic memory. We'd like to suggest some more explicit things worthy of your consideration that are intended to help the conversion from episodic to semantic memory.

Surprisingly, in the development of cognitive load theory that has been a principal area for study in instructional design, the consideration of germane load – which we could describe unceremoniously as thinking – did not emerge until the last decade. Therefore, the literature in this area is thin. We'll remind you of some important aspects of content-specific thinking, and then move to generalities.

Critical thinking and problem solving in the ULM involve both continued search for new sensory input (new information) and restructuring and transforming available sensory input into different configurations for the purpose of achieving a pattern match for LTM retrieval.

Content-Specific Thinking

Every discipline has its own way of thinking. Doctors think like doctors, lawyers think like lawyers, police officers think like police officers, and so on. If you are teaching a discipline, as in most high school and college teaching, you need to become familiar with the ways of thinking in that discipline and try to convey that to your students.

In the chemistry of carbon compounds, for example, we expect each carbon atom in a molecule to have four chemical bonds or connections to other atoms. Organic chemists automatically check for this. Whenever a molecule is represented with a carbon atom having either more or fewer than four bonds, we either predict special reactivity for that atom or suspect that an error has been made in the representation. In mathematics, we learn that multiplying an entity in an equation by one (unity) leaves that entity unchanged. Sometimes we get to be very clever in the way we write one (unity). For example, we might write one as $((\sin x)/(\sin x))$. When studying herd animals, we expect there to be an alpha animal – a leader from whom most or all other animals take their lead. When studying economics, we expect savings to equal spending. When studying psychology, we expect behavior that is rewarded to occur more frequently. When studying spread of viral disease, we need to consider airborne transmission as a mechanism. We expect the eating habits of children to be more like those of their parents than anyone else.

Each discipline has its rules, and sometimes these can be very complex. Sometimes the rules can be simple but not easily verified. Given only four colors, one can uniquely color a map so that no two adjacent entities have the same color – the so-called four-color theorem. Though first proposed in 1852, this theorem was not "proven" until 1976, a proof that has led to other improvements and proof strategies.[3]

Have Students Anticipate (Expectancy-Driven Methods)

In an expectancy-driven method, the learner anticipates an outcome and then matches that expectation against feedback about the outcome. Renkl proposed this approach in studying probability.[4] A similar result was found when asking learners to anticipate the functioning of a machine before seeing an animation of that device.[5] We think that the *discrepant event* used in science education generates situational interest. In this sequence the teacher indicates that she will do xyz and asks the students to predict the outcome. The teacher then does xyz, and the students get to compare their predictions with the actual outcome. As the label suggests, the events are selected such that the predications most often prove wrong. That is, events are selected such that a discrepancy between the likely prediction and the actual outcome is anticipated. For example, a weight is hung from a rubber band, and the teacher says: "I'm going to heat this rubber band with hot air from this hair dryer. What will happen?" The students most often predict that the rubber band will soften and the weight will go lower (i.e., the band will stretch). In fact, the rubber band contracts and the weight rises – unless you heat it enough to destroy it. This effect can be built into more complex if classic demonstrations.[6]

From the perspective of the ULM, the expectancy-driven method provides opportunity for new chunk building and new connections. Discrepant events tend to attract attention, so they can focus students' attention on the material. As students encounter the discrepancy between their prediction and the outcome, they have opportunity to examine and transform the connections in their existing knowledge that were incorrect in light of the new information provided by the discrepant outcome. The discrepancy serves to weaken existing elements of the chunks inconsistent with the new information and strengthen new connections that incorporate the experienced outcomes. Follow-up discussion can help further weaken incorrect knowledge and strengthen the new connections.

Everyone reading this book is most likely using an expectancy-driven method for constructing meaning. Proficient readers automatically make predictions about what they will be reading. They do this by looking at the title of the book. They predict what a section will be about from the chapter titles, subheadings, and any illustrations the author has included. As they read, good readers confirm or disconfirm their predictions, sometimes causing them to reread to be sure they read a sentence or passage correctly. This recursive act is not automatic for beginning readers or students of any age who struggle with reading. These children need explicit instruction and practice in how to predict as they read. As novice readers become more facile in using prediction, they begin to focus their attention better on monitoring their comprehension and resolving prediction discrepancies when they arise.

Teachers Create Sub-goals (Parse the Intrinsic Load)

What can the teacher, trainer, or instructional designer do when a learning task is very difficult? The standard approach is to divide the task into subtasks so that the learner's working memory capacity is not overloaded with new input; in cognitive load theory terms, reduce the intrinsic load of each subtask so that it is within the learner's grasp. In ULM terms, insure that the amount of material to be learned doesn't exceed the learners' working memory capacity. As we have discussed, the learner's working memory capacity is increased by prior knowledge, so more knowledgeable students can handle more input and deal with more complex manipulations of information. Vygotsky noted this need to adapt learning materials to the learners' capacity as matching the learner's zone of proximal development. Catrambone was among those to detail this approach to teaching complex problem solving.[7] This approach also accounts for some of the success found when using worked-examples during instruction. When a student views (or memorizes) a solved problem, the steps can be accessed as sub-goals and used to reduce the overall intrinsic load.

Sub-goals are potentially important for a different reason. When a novice learner is working near mental capacity, there is little available working memory capacity to "think" about the problem being worked on, to see how the current step and goal fits with other steps and goals. Winne expressed this in terms of the load placed by self-regulation upon some beginning learners. If learners have to manage too much of the learning environment themselves, they may be unable to devote sufficient capacity to creating the transformations and connections necessary for effective learning.

Remove the Scaffolding

As students become better problem solvers in a given area such as learning to read, their thinking improves when instructional scaffolding is lowered or removed. In the 1980s Pearson and Gallagher called this the Gradual Release of Responsibility Model of Instruction.[8] The term from behavioral approaches to this instructional strategy for enhancing thinking is fading.[9] Fading, or gradual release, is one of the most powerful techniques for helping learners decide when to apply particular strategies. Research has shown a variety of instructional choices that can support and advance learning more quickly than others. Reciprocal teaching, where individuals take on teaching roles within small groups, appears unusually effective.[10]

Have Students Imagine Outcomes

There are two ways to envision some sort of psychomotor process: where you want to be, or how you are going to get there. For example, think about teaching someone to throw darts. In the "internal" approach, you ask them to concentrate on holding and manipulating the dart. In the "external" approach, you ask them to focus on the target and do what it takes to strike the center of the target. A review concludes that numerous studies "... provide converging evidence that an external focus of attention (i.e., focus on the movement effect) is more effective than an internal focus (i.e., focus on the movements themselves)."[11] In a fashion similar to that found for improving psychomotor skills, similar outcomes are found for cognitive skills, but the results are mixed.[12] For students who have the schema in place, imagining works successfully. For those without the schema, imagining does not work so well. This seems to be the same load issue talked about by Winne, namely, when a novice student is near working memory capacity, there's no extra capacity for the kind of thinking that imagination requires. Once past this, however, imagination becomes a useful thinking tool that enhances learning performance.

Accommodate Cognitive Artifacts

American resurgence of interest in science teaching in the 1950s, following closely the launch of Sputnik, led to changes that included emphasis on calculations. Slide rules were devices required of science and engineering students; a slide rule case dangling from one's belt was a give-away about his or her vocation. Electric calculators were available; access to a Monroe calculator was a status symbol. An Wang, founder of Wang Laboratories, developed an electronic calculator. All of this change was dwarfed in 1972 by the emergence of the HP-35 from Hewlett Packard, the world's first "pocket calculator." The science education literature started to fill with papers about the use of calculators – and whether such usage was "fair." Soon calculator ownership became expected of students as prices dropped to the same level as textbooks. Today, high quality graphing calculators are a bit less expensive than most science textbooks!

Something else was happening during the post-Sputnik era: science curricula came to expect very extensive calculations from those who would be labeled "successful" students. In the late twentieth century, it became clear that students were able to compute quantities accurately without having any contextual understanding of what those numbers meant. Quantitative approaches were labeled as algorithmic; algorithmic became a dirty word.

Donald Norman described the tools we use to make our cognitive lives easier *cognitive artifacts*.[13] He makes the important point that these tools change the task. There was a time a few decades ago when a graduating engineer could make a living by solving differential equations. While the task remains important, the procedures have changed so much that having this as a near single skill set is of extremely limited value. Tools such as *Mathematica* enable performing such tasks in a way that has led to significant raising of the intellectual bar.[14] Salomon noted that technology tools produce two effects.

Like Norman's cognitve artifacts, there are effects with technology where the tool allows increased performance. The expertise of the human – tool system is greater than the expertise of either the person or the tool individually. Then there are effects of technology or how the technology impacts the person using it. Something like a computer based writing assistant with an idea generator and word processor can have an effect with a student allowing them to produce a better essay. Also, there is the potential that the interaction with the writing assistance can have an effect of helping the student become a better writer. Salomon thought that for this to happen the tool had to activate higher order thinking or provide a model of higher order skill that the learner could learn.[15]

Experts Practice Deliberately

What do experts do that make them stay experts? Among other things, experts practice. Experts develop routines.[16]

We often hear it said that some people are invested with special talents that are unique. Perhaps. But as we've already noted, talent is probably a word that a teacher wants to expunge. If you embrace this term, then it is better to speak of talent as something one acquires through life, rather than something one has from birth.

When experts are studied, several consistent observations are made. Experts usually have external support – from the likes of family and/or friends.[17] They have access to prior expertise through materials such as those found in a library. They have a mentor or coach. Perhaps most important, they engage in what has been termed *deliberate practice*.[18] Two renowned athletes, Michael Jordan and Tiger Woods, are famous for their dedication to practice. When athletes practice, it's usually obvious – one can watch them! Not so with writers or surgeons or plumbers.

What's the difference between ordinary practice and deliberate practice? In ordinary practice, you are trying to automate some processes; in deliberate practice, you are processing in working memory with the intent either of developing or changing a process. In deliberate practice, you are thinking about some details of what you are doing, possibly with the intent of changing them. We've mentioned more than once the lengths Tiger Woods went to when "changing his swing."[19]

A problem with changing processes that are automated is that they do not come into working memory and take up space. To modify an automated process, we must somehow consciously bring it into working memory where we can work on some aspect of that process. During much routine work, we really don't want to be thinking about what we're doing, especially when we are experts. The expert urologist performs a nerve-sparing prostatectomy and needs to seek and dissect around the neurovascular bundle. She can't be thinking about "how to hold the knife" or "how to control the robot." Before being called a surgeon, long before they are experts, they *do* have to think about how to hold the knife! That's a time when they engage in deliberate practice. If something causes them to think that a skill is slipping – perhaps holding the knife – then they need to return to practice that skill.

Reading is a skill that essentially everyone needs. Even the best readers usually can get better through deliberate practice. If you are reading this book, your decoding almost certainly is automated. Suppose we taught you a new reading comprehension strategy that involved asking and answering questions about the relationships between theory and practice. Certainly, you would have to think about your reading as you learned when and how to use the new strategy. If your reading comprehension stayed automatic and problem free, how would you practice this new strategy and know when to use it? Once you begin to master the new strategy, then you can stop thinking about your automated reading skills. One way to teach struggling readers is to focus on their procedural knowledge of comprehension strategies. More specifically, to discuss what good readers do. Researchers have discovered the practices of good (or expert) readers. The knowledge gained from understanding the automatic procedures used by expert readers is turned into a blueprint for practicing with less able readers and leads to gains in their reading ability.[20]

Conceptual Change

Conceptual change receives unusual attention in education for two reasons. First, most education and especially science education is directed at students' gaining conceptual understanding of the material rather than simple rote factual memorizing. Second, many teachers, especially science teachers, are concerned that students come to their classrooms with misconceptions they have developed from their everyday experience, and teachers are often faced with trying to change these pre-existing concepts. Students go to lengths to hang on to existing notions rather than change.[21] Many times learners confronted with information inconsistent with their current view of the concept ignore the new information or "compartmentalize" the new and old knowledge in separate chunks by keeping mental notes of the sort "but X behaves like Y and not Z in this case." In other words, it's like: "Note to self – in school, say Y instead of Z or you'll be wrong."

Considerable empirical and theoretical work has been directed at attempting to explain conceptual change as evidenced by a number of recent reviews and theory papers.[22] In Chapter 4, we extensively discussed how concepts are learned through chunking. In the ULM, concepts are produced by strengthening of the core characteristics of a knowledge chunk through repetition according to the law of large numbers. So the strength of a concept is a function of how often it has been repeated. Given that chunks/concepts extracted from everyday experience often have had extensive repetition, it is not surprising from the perspective of the ULM that students hang on to existing knowledge even if from a technical standpoint it is a misperception.[23] Like trying to change automatized procedural knowledge or a habitual behavior, confronting and changing highly strengthened pre-existing declarative knowledge chunks is difficult.

As we discussed in Chapter 4, changing automatized procedural knowledge requires "deliberate practice;" bringing the automatized procedure into working memory so that attention can be focused on the procedure. Confronting pre-existing conceptual knowledge is not quite analogous because concepts as declarative knowledge are always retrieved into working memory; there is nothing equivalent to automatized procedural knowledge that bypasses working memory. Getting the misperception into students' "attention" is not the problem.

By the working memory rule of association, when two separate pieces of knowledge are in working memory, they will be connected. So, when a student has retrieved a pre-existing chunk and they are presented with new knowledge while this chunk is in working memory, the new knowledge will be connected to the old.

By the rule of repetition, however, unless this new knowledge is repeated, it will quickly weaken in strength relative to the existing knowledge. If the new knowledge is mutually exclusive (i.e., the old and the new contradict each other), then either the new knowledge will be purged through active inhibition or the new knowledge will be separated into a new chunk. Think of the formation of separate dog and cat chunks out of "animal" as conflicting information about dogs and cats increases. These processes account for both the observations that students simply ignore conflicting conceptual information and that students "compartmentalize" information into broad categories of school and real world.

Like other theories of conceptual change, the ULM unfortunately does not provide an "easy" answer to how to confront students' misperceptions and replace them with more appropriate conceptual understanding. As discussed in Chapter 4, providing best exemplars of concepts and doing instruction that focuses student attention on the salient core knowledge components of the concept will build accurate concept chunks faster and more accurately. In the early grades, maybe the best that a teacher can do is to get students to acquire an accurate "alternative" conceptual chunk, even if it is compartmentalized to school. As students progress through their schooling, there will be more opportunities for the accurate conceptual knowledge to be encountered repeatedly. Hopefully this can strengthen the correct formal knowledge enough for it to ultimately replace the old naïve concept.

As we discussed previously, discrepant events might be used to highlight the differences between the alternative concepts. Certainly the more times the students bring the two contradictory concepts into working memory together, the more rapidly the repetition based concept formation processes will work. Any instructional activities from demonstrations to hands-on experiments or exercises that will make students "think" about the knowledge and any contradictions that need resolution will increase the number of transformations, repetitions, and new connections that happen. But there is no certainty that these methods will lead to replacement of the old chunk rather than compartmentalization.

Notes

1. For example, see Anderson, J. R. (2005). *Cognitive psychology and its implications* (6th edn.). New York: Worth Publishers; or Clark, R. C., Nguyen, F., & Sweller, J. (2006). *Efficiency in learning: Evidence-based guidelines to manage cognitive load.* San Francisco: Pfeiffer.
2. Winne, P. H. (1995). Inherent details in self-regulated learning. *Educational Psychologist, 30*, 173–188.
3. http://en.wikipedia.org/wiki/Four_color_theorem (Accessed March 23, 2009).
4. Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. *Cognitive Science, 21*(1), 1–29.
5. Hegarty, M., Kriz, S., & Cate, C. (2003). The roles of mental animations and external animations in understanding mechanical systems. *Cognition and Instruction, 21*(4), 209–249.
6. http://demo.physics.uiuc.edu/lectdemo/scripts/demo_descript.idc?DemoID=578 (Accessed March 23, 2009).
7. Catrambone, R. (1998). The subgoal learning model: creating better examples so that students can solve novel problems. *Journal of Experimental Psychology. General, 127*, 355–376.

8. Pearson, P. D., & Gallagher, M.C. (1983). The instruction of reading comprehension. *Contemporary Educational Psychology, 8(3),* 317–344.
9. Reisslein, J., Reisslein, M., & Seeling, P. (2005, October 19–22, 2005). WIP: Effectiveness of worked examples and fading in introductory electrical circuit analysis for learners of different ability levels. Paper presented at the Frontiers in Education, 2005. FIE '05. Proceedings 35th Annual Conference, Indianapolis.
10. Palincsar, A. S., & Brown, A. (1984). Reciprocal teaching of comprehension fostering and monitoring activities. *Cognition and Instruction, 1*, 117–175; Brown, A. L., & Campione, J. C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 229–270). Cambridge, MA: The MIT Press.
11. Wulf, G. (2007). Attentional focus and motor learning: A review of 10 years of research. *Gabriele Wulf on attentional focus and motor learning. E-Journal Bewegung und Training, 1*, 4–14.
12. Cooper, G., Tindall-Ford, S., Chandler, P., & Sweller, J. (2001). Learning by imagining. *Journal of Experimental Psychology Applied, 7*(1), 68–82.
13. Norman, D. A. (1991). Cognitive artifacts. In J. M. Carroll (Ed.), *Designing interaction* (pp. 17–38). Cambridge: Cambridge University Press.
14. http://www.wolfram.com/products/mathematica/index.html (Accessed March 23, 2009).
15. Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher*, *20*(3), 2–9.
16. Kiewra, K., & Creswell, J. (2000). Conversations with three highly productive educational psychologists: Richard Anderson, Richard Mayer, and Michael Pressley. *Educational Psychology Review, 12*(1), 135–161.
17. Gardner, H. (1998). *Extraordinary minds*. New York: BasicBooks; Gladwell, M. (2008). *Outliers: The story of success*. New York: Little, Brown, and Company; Bloom, B., & Sosniak, L. (1985). *Developing talent in young people*. New York: Ballantine Books.
18. Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Rev*iew, *100*(3), 363–406; Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In K. A. Ericsson, N. Charness, P. J. Feltovich & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 683–703). New York: Cambridge University Press.
19. http://www.oneplanegolfswing.com/oneplanemembers/Tour_Pros/Tiger-Woods/index.jsp (Accessed March 23, 2009).
20. Paris, S. G., Cross, D. R., & Lipson, M. Y. (1984). Informed strategies for learning: A program to improve children's reading awareness and comprehension. *Journal of Educational Psychology, 76*, 1239–1252; Pressley, M., Borkowski, J. G., & Schneider, W. (1987). Cognitive strategies: Good strategy users coordinate metacognition and knowledge. In R. Vasta & G. Whitehurst (Eds.), *Annals of child development* (Vol. 5, pp. 89–129). Greenwich, CT: JAI Press.
21. Chinn, C. A., & Brewer, W. F. (1993). The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction. *Review of Educational Research, 63*, 1–50.
22. Vosniadou, S., Baltas, A., & Xenia, V. (Eds.). (2007). *Reframing the conceptual change approach in learning and instruction*. New York: Elsevier Science.; Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20–40; the entire 1st issue of volume 44 of *Educational Psychologist*; Ohlsson, S. (2009). Resubsumption: A possible mechanism for conceptual change and belief revision. *Educational Psychologist, 44*(1), 20–40; Chi, M., & Brem, S. (2009). Contrasting Ohlsson's resubsumption theory with Chi's categorical shift theory. *Educational Psychologist, 44*(1), 58–63.

23. While there is considerable interest in concept change, the distinction between “to know” and “to believe” has a long history. People differ in the ways in which they distinguish knowledge from belief. One way in which this is done is in terms of degree of conviction. A discussion of this question far exceeds what we intend for this book. An interesting starting discussion can be found in Markham, A. B. (1999). *Knowledge representation.* Mahwah, NJ: Lawrence Erlbaum Associates (pp. 72–75).