Chapter 3

COGNITIVE TRANSFORMATION THEORY: CONTRASTING COGNITIVE AND BEHAVIORAL LEARNING

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The traditional approach to learning is to define the objectives (the gap between the knowledge a person has and the knowledge the person needs to perform the task), establish the regimen for practice, and provide feedback. Learning procedures and factual data are seen as adding more information and skills to the person's storehouse of knowledge. However, this storehouse metaphor is poorly suited for cognitive skills and does not address the differing learning needs of novices and experts. Teaching cognitive skills requires the diagnosis of the problem in terms of flaws in existing mental models, not gaps in knowledge. It requires learning objectives that are linked to the person's current mental models, practice regimens that may have to result in "unlearning" that enables the person to abandon the current, flawed mental models, and it requires feedback that promotes sensemaking. We propose a Cognitive Transformation Theory to guide the development of cognitive skills. We also present several strategies that might be useful in overcoming barriers to understanding and to revising mental models. Finally, we show the implications of Cognitive Transformation Theory for using virtual environments (VEs; where a "live" student interacts with a "simulated" environment) in training.

INTRODUCTION

How can cognitive skills be improved? The conventional mechanisms of practice, feedback, and accumulation of knowledge rarely apply to cognitive skills in the same way they apply to behavioral skills. In this chapter we argue that cognitive learning requires a different concept of the learning process.

Traditional approaches to learning seem clear-cut: (1) identify what you want the student to learn; (2) provide the knowledge and present an opportunity to practice the skill or concept; (3) give feedback so the student can gauge whether the learning has succeeded. Educating students in behavioral skills appears to simply be a matter of practice and feedback.

This approach to learning relies on a storehouse metaphor. It assumes that the learner is missing some critical form of knowledge—factual information or procedures. The learner or the instructor defines what knowledge is missing. Together, they add this knowledge via a course, a practice regimen, or through simple study. Instructors provide feedback to the learner. Then, they test whether the new knowledge was successfully added to the storehouse.

We believe that this storehouse metaphor is insufficient to describe learning of cognitive skills. The storehouse metaphor may be useful for learning factual information or for learning simple procedures. But cognitive learning should help people discover new ways to understand events. We can distinguish different forms of knowledge that people need in order to gain expertise: declarative knowledge, routines and procedures, recognition of familiar patterns, perceptual discrimination skills, and mental models.

The storehouse metaphor seems best suited for acquiring declarative knowledge and for learning new routines/procedures. It may be less apt for building pattern-recognition skills. It is least appropriate for teaching people to make perceptual discriminations and for improving the quality of their mental models.

When people build a larger repertoire of patterns and prototypes, they are not simply adding new items to their lists. They are learning how to categorize the new items and are changing categories and redefining the patterns and prototypes as they gain new experience. The storehouse metaphor implies a simple additive process, which would lead to confusion rather than to growth. We encounter this kind of confusion when we set up a new filing system for an unfamiliar type of project and quickly realize that adding more files is creating only more confusion—the initial categories have to be changed.

When people develop perceptual discrimination skills through training in VEs or other methods, they are learning to make distinctions that they previously did not notice. They are learning to "see the invisible" (Klein & Hoffman, 1993) in the sense that they can now make discriminations they previously did not notice. Perceptual learning depends on refashioning the way we attend and the way we see, rather than just adding additional facts to our knowledge base.

Cognitive skills depend heavily on mental models. We define a mental model as a cluster of causal beliefs about how things happen. We have mental models for how our car starts when we turn our key in the ignition, for how water is forced out of a garden hose when the spigot is turned on, and for why one sports team has beaten another. In steering a simple sailboat, we have a mental model of why the nose of the boat will turn to the left when we press the tiller to the right. We believe that the water will press against the rudder in a way that swings the back of the boat to the right, creating a counterclockwise rotation in the boat's heading. Therefore, the slower the boat moves, the less the water pressure on the rudder and the less pronounced this effect should be. According to Glaser and Chi (1988), mental models are used to organize knowledge. Mental models are also described as knowledge structures and schemata.

Cognitive learning is not simply a matter of adding additional beliefs into the existing mental models. Rather, we have to revise our belief systems and our mental models as experience shows the inadequacy of our current ways of thinking. We discover ways to extend or even reject our existing beliefs in favor of more sophisticated beliefs.

The scientist metaphor is much more suited to cognitive learning. This metaphor views a learner as a scientist engaged in making discoveries, wrestling with anomalies, and finding ways to restructure beliefs and mental models (Carey, 1986). The scientist metaphor is consistent with the field of science education, where students are taught to replace their flawed mental models with better concepts about how physical, chemical, and biological processes actually work. The scientist metaphor emphasizes conceptual change, not accumulation of declarative information. Within psychology, the scientist metaphor is epitomized by Piaget (1929) who described conceptual change as a process of *accommodation*. Posner, Strike, Hewson, and Gertzog (1982) point out that within the philosophy of science, the empiricist tradition that evaluated a theory's success in generating confirmed predictions has been superseded by views that emphasize a theory's resources for solving problems. This replacement fits better within the Piagetian process of accommodation than does the empiricist approach. Posner et al. have described some of the conditions necessary for accommodation to take place: dissatisfaction with existing conceptions, including the difficulties created by anomalies; the intelligibility of new concepts, perhaps by linkage with analogies and metaphors; and the initial plausibility of new conceptions.

Although our own approach is firmly within the scientist metaphor, we should note some disconnects. The field of science education assumes a knowledgeable teacher attempting to convince students to accept scientifically acceptable theories. In contrast, many cognitive learning situations do not come equipped with knowledgeable teachers, and the learners have to discover for themselves where their mental models are wrong and how to replace them with more effective ones.

The next section describes the kinds of sensemaking needed for cognitive learning. Following that, we present the concept of cognitive transformation as an alternative to the storehouse metaphor, and as an elaboration of the scientist metaphor. Finally, we offer some implications for achieving cognitive learning in virtual environments.

SENSEMAKING REQUIREMENTS FOR LEARNING COGNITIVE SKILLS

What is hard about learning cognitive skills is that none of the traditional components of learning—diagnosis, practice, feedback, or training objectives—are straightforward. Each of them depends heavily on sensemaking (for example, Weick, 1995). Bloom's (1956) taxonomy includes a component of synthesis—building a structure or pattern from diverse elements; and putting parts together to form a whole, with an emphasis on creating a new meaning or structure. This corresponds to the process of sensemaking.

We treat cognitive learning as a *sensemaking* activity that includes four components: diagnosis, learning objectives, practice, and feedback. These components of sensemaking must be the up-front focus of any VE development in order for effective training transfer to occur.

Diagnosis

Diagnosing the reasons for weak performance depends on sensemaking. The instructor, whether in person or virtual, has to ferret out the reasons why the student is confused and making errors. Sometimes trainees do not even notice errors or weaknesses and may resist suggestions to overcome problems they do not realize they have. Even if trainees do realize something is wrong, the cause/effect mechanisms are subtle and complex. Outcome feedback, the type of feedback that is most often available in the technologies associated with virtual environments, usually does not provide any clues about what to do differently. That is why instructors and technologies need to be able to provide process feedback as the trainee progresses through the learning process, but they first must diagnose what is wrong with the trainee's thinking. Diagnosing the reason for poor performance is a challenge to trainees. It is also a challenge to the instructors who may not be able to figure out the nature of the problem and who have no technologies capable of providing a diagnosis at this level.

Diagnosis is difficult for instructional developers. The classical systems approach to instructional design is to subtract the existing knowledge, skills, and abilities (KSAs) from the needed KSAs. But for cognitive skills, instructional developers need to understand why the students are struggling. The goal of diagnosis goes beyond establishing learning objectives—it depends on discovering what flaw in a mental model needs to be corrected.

For cognitive skills, it is very difficult to determine and define the existing problem. Cognitive Task Analysis (for example, Crandall, Klein, & Hoffman, 2006) methods may be needed to diagnose subtle aspects of cognitive skills.

Within the framework of science education, Chi, Glaser, and Rees (1982) have discussed the use of misconceptions to understand why students are confused. Similarly, Shuell (1986) described how a student's "buggy algorithms" could lead to misconceptions and how analysis of mistakes can provide educators with insights into how to repair the flaws.

Learning Objectives

With the storehouse metaphor, learning objectives are clear and succinct—the additional declarative or procedural knowledge to be imparted and the changes in performance that reflect whether the student has acquired the new material.

But for cognitive learning, the objectives may be to help the students revise their mental models and perhaps to reorganize the way they categorize events. Some learning theorists emphasize the importance of integrating new learning with the concepts that are already known. For example, both Kolb (1984) and Dewey (1938) focus on learning through experience. What is important in Kolb's reflective observation stage is how the learner transforms an experience into learning through reflection. During reflection, the student compares the new learning to what is already known and tries to make it fit with existing knowledge and sees how to leverage this new knowledge for additional learning.

For Dewey, the key is what the learner does with experience. Not all experiences are equal and not all experiences are educational. According to Dewey, individuals reflect on their experiences to learn what thoughts and actions can change real world conditions that need improving. Dewey thought that people were constantly trying to resolve perplexing intellectual situations and difficult moral situations.

Theorists such as Kolb and Dewey do not view accumulating or storing knowledge as an end state. Instead, knowledge accumulation kicks off a series of cognitive activities by the individual to figure out ways to test the "goodness" of the new learning through active experimentation or to use the new learning to change an unsatisfactory situation.

The field of science education describes this process as "restructuring" (Chi et al., 1982; Shuell, 1986). Carey (1986) draws on the philosophy of science and, in particular, the work of Kuhn (1962), Feyerabend (1962), and Toulmin (1953) to describe conceptual change. When theories change, successive conceptual systems will differ in the phenomena they address, the kinds of explanations they offer, and the concepts they employ. Carey uses the example of theories of mechanics, which historically used different meanings for the terms force, velocity, time, and mass. Thus, Aristotle did not distinguish between average velocity and instantaneous velocity, whereas Galileo highlighted this difference.

Carey distinguishes weak restructuring, which simply represents additional relations and schemata (for example, the storehouse metaphor), from strong restructuring, which involves a change in the core concepts themselves. Shuell (1986) uses the term "tuning" to cover Carey's notion of weak restructuring and further notes that both tuning and restructuring resemble Piaget's concept of accommodation.

We further assert that novices may not have mental models for an unfamiliar domain and will struggle to formulate even rudimentary mental models linking causes to effects. Their learning objective is to employ sensemaking to generate initial mental models of cause/effect stories, whereas experts are revising and adding to current mental models.

Following Posner et al. (1982), we suggest that accommodation itself may be a key learning objective—creating dissatisfaction with an inadequate conception, creating openness to a superior replacement.

Practice

Providing students with practice is necessary for gaining proficiency. But with cognitive skills, practice is not sufficient. For cognitive skills, trainees often may not know what they should be watching and monitoring. They need adequate mental models to direct their attention, but until they get smarter, they may fail to spot the cues that will help them develop better mental models.

VE can help trainees gain this needed practice in a context that allows them to build more robust mental models. Waller, Hunt, and Knapp (1998) found that while short VE training periods were no more effective than paper and pencil exercises, with sufficient exposure to a virtual training environment, VE training actually surpassed real world training. Numerous studies have supported the effectiveness of VEs. Brooks, Fuchs, McMillan, Whitton, and Cannon-Bowers (2006) found that VEs can provide a higher density of experiences and the chance to practice rare and dangerous scenarios safely, and Witmer, Bailey, and Knerr (1995) validated the ability of VE training to transfer to real world settings in a study they conducted with the training of dismounted soldiers in virtual environments.

Managing attention depends on sensemaking. Feedback will not be useful if the trainee does not notice or understand it—and that requires the trainee to know what to attend to and when to shift attention. Barrett, Tugade, and Engle (2004) have suggested that attention management accounts for many of the individual differences in working memory—the ability to focus attention and not be distracted by irrelevancies. For these reasons, we argue that effective practice, whether in actual or in virtual environments, depends on attention management: seeking information—knowing what to seek and when to seek it—and filtering distracting data.

Feedback

Providing students with feedback will not be useful if they do not understand it. For complex cognitive skills, such as leadership, time lags between actions and consequences will create difficulties in sorting out what worked, what did not work, and why. Learners need to engage in sensemaking to discover cause-effect relationships between actions taken at time one and the effects seen at time two. To make things more complicated, learners often have to account for other actions and events that are interspersed between their actions and the consequences. They have to figure out what really caused the consequences versus the coincidental events that had nothing to do with their actions. They have to understand the causes versus the symptoms of deeper causes, and they have to sort out what just happened, the factors in play, the influence of these factors, and the time lags for the effects.

To add to these complications, having an instructor or training tool provide feedback can actually get in the way of transfer of learning (Schmidt & Wulf, 1997) even though it increases the learning curve during acquisition. By placing students in an environment where they are given rapid feedback, the students are not compelled to develop skills for seeking their own feedback. Further, students may become distracted from intrinsic feedback because it is so much easier to rely on the extrinsic feedback. As a result, when they complete what they set out to learn, they are not prepared to seek and interpret their own feedback.

One of the challenges for cognitive learning is to handle time lags between actions and consequences. VE sessions will compress these time lags, which might clarify relationships but will also reduce the opportunity to learn how to interpret delayed feedback. To compensate, VE sessions could add distracters that might have potentially caused the effects as a way to sustain confusion about how to interpret feedback. In addition, VE sessions could be structured to monitor how people interpret the feedback.

For cognitive learning, one of the complications facing instructional designers is that the flawed mental models of the students act as a barrier to learning. Students need to have better mental models in order to understand the feedback that would invalidate their existing mental models. Without a good mental model, students will have trouble making use of feedback, but without useful feedback, students will not be able to develop good mental models. That is why cognitive learning may depend on unlearning as well as learning.

THE PROCESS OF UNLEARNING

For people to develop better mental models they may have to unlearn some of their existing mental models. The reason is that as people gain experience, their understanding of a domain should become more complex and nuanced. The mental models that provided a rough approximation need to be replaced by more sophisticated ones. But people may be reluctant to abandon inadequate mental models, as they may not appreciate the inadequacies. They may attempt to explain away the inconsistencies and anomalies. A number of researchers have described the reluctance to discard outmoded mental models even in the face of contrary evidence. DeKeyser and Woods (1990) have commented on the way decision makers fixate on erroneous beliefs. Feltovich, Spiro, and Coulson (1997) used a garden path paradigm and identified a range of knowledge shields that pediatric cardiologists employed to discount inconvenient data.

Chinn and Brewer (1993) showed that scientists and science students alike deflected inconvenient data. They identified seven reactions to anomalous data that were inconsistent with a mental model: ignoring the data, rejecting the data, finding a way to exclude the data from an evaluation of the theory/model, holding the data in abeyance, reinterpreting the data while retaining the theory/model, reinterpreting the data and making peripheral changes to the theory/model, and accepting the data and revising the theory/model. Only this last reaction changes the core beliefs. The others involve ways to discount the data and preserve the theory.

Klein, Phillips, Rall, and Peluso (2006) described the "spreading corruption" that resulted when people distorted data in order to retain flawed mental models. As people become more experienced, their mental models become more sophisticated, and, therefore, people grow more effective in explaining away inconsistencies. Fixations should become less tractable as cognitive skills improve. Therefore, people may have to unlearn their flawed mental models before they can acquire better ones. Sensemaking here is a deliberate activity to discover what is wrong with one's mental models and to abandon and replace them. Oftentimes, VEs can allow trainees to see the flaws in their mental models by illustrating the potential behavioral outcomes of their current cognitive processes. Being able to understand these flaws is critical for the unlearning process and enabling accommodation.

The process of unlearning that we are presenting resembles the scientific paradigm replacements described by Polanyi (1958) and Kuhn (1962). Another philosopher of science, Lakatos (1976), explained that researchers more readily change their peripheral ideas to accommodate anomalies than their hard-core ideas on which the peripheral ideas are based. As expected, the notion of disconfirmation is central to science education because of the importance and difficulty of changing students' naive theories. And just as scientists resist changing their theories when exposed to disconfirming evidence, so do students. Eylon and Linn (1988) reviewed studies showing that students can be impervious to contradictions. According to Chinn and Brewer (1993), the more a belief is embedded in supporting data and concepts and is used to support other concepts, the greater the resistance. Further, the anomalous data need to be credible, nonambiguous, and presented in concert with additional data in order to have the necessary impact, which presents additional requirements for effective use of VEs.

The term "unlearning" is widely used in the field of organizational learning. Starbuck and Hedberg (2001) stated that "Organizations' resistance to dramatic reorientations creates a need for explicit unlearning . . . Before attempting radical changes, [organizations] must dismantle parts of their current ideological and political structures. Before they will contemplate dramatically different procedures, policies, and strategies, they must lose confidence in their current procedures, policies, strategies, and top managers" (p. 339). We believe that these observations apply to individuals as well as to organizations and that the concept of unlearning needs to become part of a cognitive learning regimen.

Just like organizations, individuals also resist changing their mental models. Chinn and Brewer (1993) refer to Kuhn's (1962) research to suggest that students will be more likely to abandon a flawed set of beliefs if they have an alternative theory/model available. This method may work best when the alternative model is already part of the students' repertoire. For example, Brown and Clement (1989) tried to teach students about the balance of forces in operation when a book is resting on a table. The students initially refused to believe that the table exerts an upward force on the book. So they were asked to imagine that they were supporting a book with their hand. Clearly, their hand was exerting force to keep the book from falling. Next, the students were told to imagine that the book was balanced on a spring. Next, they imagined a book balanced on a pliable wooden plank. Eventually, many of the students came to accept that the solid table must be exerting an upward force on the book. This type of gradual introduction of alternative analogies seems very promising. The alternative explanations make it easier to give up the flawed mental model.

However, in some situations we suspect that the reverse has to happen. People have to lose confidence in their models before they will seriously consider an alternate. Thus, DiBello and her colleagues developed a two-day program that created a VE to help managers think more effectively about their work (DiBello, 2001). The first day was spent in a simulation of their business designed to have the managers fail in the same ways they were failing in real life. This experience helped the managers lose confidence in their current mental models of how to conduct their work. The second day gave the managers a second shot at the simulated exercise and a chance to develop and use new mental models of their work. DiBello and her colleagues have recently ported their program onto *Second Life,* an Internet based virtual world video game, as a more effective means of instruction.

Schmitt (1996) designed similar experiences for the U.S. Marine Corps. His Tactical Decision Games—low fidelity paper and pencil exercises—put individual marines into situations that challenged their thinking and made them lose confidence in their mental models of tactics and leadership. The exercises, like the more technologically advanced VE, provided a safe environment for rethinking some of their closely held beliefs. When the Tactical Decision Games were presented via a VE format, the stress and training impact appear to have been sustained.

Scott, Asoko, and Driver (1991) have described two broad types of strategies for producing conceptual change: creating cognitive conflict and building on existing ideas as analogies. The DiBello and Schmitt approaches fit within the first grouping, to create cognitive conflict. The Brown and Clement work exemplifies the second—introducing analogs as platforms for new ideas.

Chinn and Brewer (1993) have also suggested that asking students to justify their models will facilitate their readiness to change models in the face of anomalous data.

Rouse and Morris (1986) have voiced concerns about invoking the notion of mental models. The concept of a mental model is typically so vague and ambiguous that it has little theoretical or applied value. However, Klein and Hoffman (2008) argue that the term "mental model" is an umbrella that covers a variety of relationships: causal, spatial, organizational, temporal, and so forth. As long as we are clear about which type of relationship we are interested in, much of the murkiness of "mental models" disappears. Doyle and Ford (1998) presented a useful account of mental models of dynamic systems, which they defined as a relatively enduring and accessible, but limited, internal conceptual representation of an external system whose structure maintains the perceived structure of that system. They differentiated their account from the concept of "mental representations," which covers a variety of cognitive structures such as schemas, images, scripts, and so forth.

With regard to cognitive learning, our emphasis is usually on causal relationships. During the learning process, people are engaged in sensemaking to understand and explain how to make things happen. Under the right circumstances, they may also discover better ways to think about causal connections.

People have to diagnose their performance problems, manage their attention, appreciate the implications of feedback, and formulate better mental models by unlearning inadequate models. Learners are not simply accumulating more knowledge into a storehouse. They are changing their perspectives on the world.

That is why we hypothesize that these changes are uneven, rather than smooth and cumulative.

COGNITIVE TRANSFORMATION THEORY

In this section we present an account of the transition process for acquiring cognitive skills. We are primarily interested in how people learn better mental models to achieve a stronger understanding of what has been happening and what to do about it. In contrast to a storehouse metaphor of adding more and more knowledge, we offer the notion of cognitive transformation—that progress in cognitive skills depends on successively shedding outmoded sets of beliefs and adopting new beliefs. We call this account of cognitive learning "Cognitive Transformation Theory" (CTT).

Our central claim is that conceptual learning is discontinuous rather than smooth. We make periodic advances when we replace flawed mental models with better ones. However, during the process of cognitive development our mental models get harder to disconfirm. As we move further up the learning curve or have more expertise, we have to put more and more energy into unlearning—disconfirming mental models—in order to accept better ones.

We do not smoothly acquire knowledge as in a storehouse metaphor. Our comprehension proceeds by qualitative jumps. At each juncture our new mental models direct what we attend to and explain away anomalies. As a result, we have trouble diagnosing the flaws in our thinking. Because of problematic mental models, people often misdiagnose their limitations and discard or misinterpret informative feedback. The previous mental model, by distorting cues and feedback, acts as a barrier to advancement. So progress may involve some backtracking to shed mistaken notions. In addition, flawed beliefs have also influenced the way people encoded experiences in the past. Simply changing one's beliefs will not automatically change the network of implications generated from those beliefs. As a result, people may struggle with inconsistencies based on different mental models that have been used at different times in the past.

Instructional developers have to design interventions that help trainees unlearn their flawed mental models.

We can represent cognitive transformation theory as a set of postulates:

- Mental models are central to cognitive learning. Instruction needs to diagnose limitations in mental models, design interventions to help students appreciate the flaws in their mental models, and provide experiences to enable trainees to discover more useful and accurate mental models.
- Mental models are modular. People have a variety of fragmentary mental models, and they weave these together to account for a novel observation. People are usually not matching events to sophisticated theories they have in memory. They are using fragments and partial beliefs to construct relevant mental models. For most domains, the central mental models describe causal relationships. They describe how events transform into later events. Causal mental models typically take the form of a story.

- Experts have more sophisticated mental models in their domains of practice than novices. Experts have more of the fragmentary beliefs needed to construct a plausible mental model. Therefore, they are starting their construction from a more advanced position. Finally, experts have more accurate causal mental models and have tested and abandoned more inadequate beliefs.
- Experts build their repertoires of fragmentary mental models in a discontinuous fashion. In using their mental models, even experts may distort data, oversimplify, explain away diagnostic information, and misunderstand events. At some point, experts realize the inadequacies of their mental models. They abandon their existing mental models and replace these with a better set of causal beliefs. And the cycle begins again.
- Learning curves are usually smooth because researchers combine data from several subjects. The reason for the smoothness is the averaging of discontinuous curves.
- Experts are fallible. No set of mental models is entirely accurate and complete.
- Knowledge shields are the set of arguments learners can use to explain away data that challenge their mental models (Feltovich et al., 1997). Knowledge shields pose a barrier to developing cognitive skills. People are skilled at holding onto cherished beliefs. The better the mental models, the easier it is to find flaws in disconfirming evidence and anomalous observations. The S-shaped learning curve reflects the increasing difficulty of replacing mental models as people's mental models become more accurate.
- Knowledge shields affect diagnosis. Active learners try to overcome their limitations, but they need to understand what those limitations are. Knowledge shields based on poor mental models can lead learners to the wrong diagnoses of their poor performance.
- Knowledge shields affect feedback. In building mental models about complex situations, people receive a lot of feedback. However, the knowledge shields enable people to discard or neutralize contradictory data.
- Progress depends on unlearning. The better the causal models, the more difficult it is to discover their weaknesses and replace them. In many cases, learners have to encounter a baffling event, an unmistakable anomaly, or an intelligent failure in order to begin doubting their mental models. They have to lose faith in their existing mental models before they can review the pattern of evidence and formulate a better mental model. People can improve their mental models by continually elaborating them, by replacing them with better ones, and/or by unlearning their current mental models. Cognitive development relies on all three processes.
- Individual differences in attitudes toward cognitive conflict will affect success in conceptual change. Dreyfus, Jungwirth, and Eliovitch (1990) noted that bright and successful students responded positively to anomalies, whereas unsuccessful students tended to avoid the conflicts.

Cognitive Transformation Theory generates several testable hypotheses. It asserts that individual learning curves will be discontinuous, as opposed to the smooth curves found when researchers synthesize data across several subjects. CTT suggests a form of state-dependent learning. The material learned with one set of mental models may be inconsistent with material learned with a different mental model. Consequently, learners may be plagued with inconsistencies that reflect their differing beliefs during the learning cycle.

IMPLICATIONS FOR VIRTUAL ENVIRONMENTS

What is difficult about learning cognitive skills in virtual environments? While on the surface, there can appear to be tremendous benefits to taking advantage of virtual environments and the associated technologies to support cognitive skill development, Koschmann, Myers, Feltovich, and Barrows (1994) note that technology in environments often seems to be focused on the capabilities of the technology rather than on the instructional need. In essence, they are often technology focused learning with learning as an afterthought.

Virtual environments are becoming integral to almost all areas of training and educational applications. These virtual environments can include projector based displays, augmented and mixed reality technologies, online structured professional forums, game based learning technologies, and multimodal technologies to name a few. As with the more traditional types of learning discussed in this chapter, Cognitive Transformation Theory can guide the way we develop and use these technologies.

Cognitive Transformation Theory revolves around the principle that mental models are central to cognitive learning. Virtual environments give us the opportunity to examine our mental models and build on them. Simulated environments can allow learners to see how a proposed path of action plays out, thereby allowing them to observe flaws in their mental models and begin the process of improving mental models.

In addition, virtual environments allow for both intrinsic and extrinsic feedback. Many simulations offer scoring or an after action review capability that allows learners to see how they did in comparison to other students or some set standard. More important than the extrinsic feedback, these virtual environments give learners the ability to see how their actions play out and the challenges they may run into based on their mental models, allowing for self-assessment, adjustment, and improvement in cognitive learning.

Because cognitive learning depends heavily on sensemaking, and sensemaking is often complicated by knowledge shields, virtual environment sessions might benefit from designs using garden path scenarios that elicit knowledge shields and give learners a chance to recover from mistaken mindsets and get off the garden path. In a garden path scenario a person is led to accept a proposition that seems obviously true and is then given increasing amounts of contrary evidence gradually leading to the realization that the initial proposition is wrong. The paradigm lets us study how long it takes for participants to doubt and then reject the initial proposition—how long they stay on the garden path.

Virtual environments may also support some of the strategies that Posner et al. (1982) described for facilitating accommodation by helping instructors to diagnose errors and also prepare for the defenses trainees might employ as knowledge shields and by helping instructors track the process of concept change.

CONCLUSIONS

Now we can see what is wrong with the storehouse metaphor of learning described at the beginning of this paper. Learning is more than adding additional information. Learning is about changing the way we understand events, changing the way we see the world, changing what counts as information in the first place. The functions of diagnosis, practice, and feedback are all complex and depend on sensemaking.

To replace the storehouse metaphor we have presented a theory of cognitive transformation. We claim that cognitive skills do not develop as a continual accumulation. Rather, cognitive skills and the mental models underlying them progress unevenly. Flawed mental models are replaced by better ones, but the stronger the mental models the more difficult to dislodge them. As a result, learners explain away anomalies, inconsistencies, inconvenient feedback, and misdiagnose their problems. How we teach cognitive skills, therefore, has to help people unlearn their current mental models before helping them develop better ones. If this unlearning process does not occur, the students will use their current mental models to discount the lessons and the feedback.

Cognitive Transformation Theory may offer a shift in perspective on cognitive learning. It relies on sensemaking as the core function in learning cognitive skills, as opposed to a storehouse metaphor.

These issues pose challenges to the use of VEs for training cognitive skills. The training cannot be treated as a matter of realistically replicating perceptual phenomena. If the technology interferes with diagnosis, distorts cognitive learning objectives, short-cuts the attention management skills needed for practice, and limits the search for and interpretation of feedback, then cognitive learning will be degraded.

Fortunately, a VE can provide a platform for unlearning that can be superior to the natural environment. To be effective for cognitive learning, VE approaches will need to move beyond increasing sensory realism and consider the design of scenarios to promote sensemaking. Cognitive Transformation Theory offers some recommendations for how this might be done. By ensuring that the training environment supports diagnosis, attention management, and feedback, virtual environments can become useful and efficient means of achieving cognitive transformations.

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