Cognition and Learning:
Meeting the Challenge of Individual Differences

David H. Rose

Chief Research Scientist

CAST

Lecturer, Harvard University

Introduction

Recent advances in the cognitive sciences, and especially in the cognitive neurosciences, have made one thing abundantly clear – there is no simple way to characterize, or localize, cognition. The journal Cognitive Psychology takes a typical approach to this problem; instead of directly defining cognitive psychology, the journal lists the kinds of processes that are commonly included – memory, language processing, perception, problem solving, and thinking.

Unfortunately none of these processes are easily defined or categorized either. In fact, the recent explosion of imaging studies in cognitive neuroscience has demonstrated that none of these are really coherent or localizable functions at all. Few neuroscientists or cognitive scientists now think, for example, that memory, language or perception are simple or unitary functions. In fact they are all highly distributed functions anatomically, they have many different subcomponents that are activated in differing tasks and contexts, and they are surprisingly difficult to separate from each other in practice. When attention, problem solving and thinking are added to the mix, things get pretty complicated.

In this brief paper, we shall not resolve what cognition is, but will choose another common tactic – to recognize that every act of cognition involves a few broad functions that are both anatomically and psychologically distinct. While neuroscience suggests considerable complexity in any act of cognition, it is possible to identify three broad components that are recognized in both the psychological and neuropsychological research (e.g. Luria, 1973; Cytowic, (1996)). Broadly speaking, one component recognizes patterns, one generates patterns, and the third determines which of the patterns are important to us. Each of these components is involved not only in cognition generally, but in the functions that we call memory, language processing, problem solving, and possibly thinking.

Recognition Systems

Most of the posterior (back) half of the brain's cortex is devoted to recognizing patterns (e.g. Mountcastle, 1998; Farah, 1999). Pattern recognition makes it possible to identify objects in the world on the basis of the visual, auditory, tactile, and olfactory stimuli that reach our receptors. Through recognition systems we learn to know that a particular stimulus pattern is a book, a dog's bark, the smell of burning leaves. In reading, to take a more cognitive example, pattern recognition systems identify basic patterns in orthography, phonology, semantics, as well as the many higher-level patterns of written syntax, paragraph structure, story grammar, style, etc.

When recognition systems in posterior cortex are damaged or undeveloped, the brain's capacity to know what things are - to recognize objects, symbols, or signs by their perceptual properties - is compromised. From a neurological perspective there are many names for both general and specific types of recognition problems – e.g. the receptive aphasias (difficulty recognizing spoken words), the visual agnosias (difficulty recognizing objects that are seen), dyslexias (difficulty recognizing written words), amusia (difficulty recognizing the patterns in music) and so forth. Imaging studies on many types of recognition problems reveal atypical patterns of posterior activation – the work on dyslexia is a notable example (Shaywitz, 2004).

But recognition problems are not exclusively neurological in origin. The term recognition - re-cognition - emphasizes the experiential role in knowing. What we perceive, what we remember, what we are able to imagine in order to solve problems, how we can understand spoken or written language – all depend on your ability to re-cognize, to remember and reconstruct the patterns that we have previously experienced, the patterns we have learned. Re-cognition is a key part of any cognition, and any learning. But recognition is only one part of cognition.

Strategic Systems

The anterior part of the brain (the frontal lobes) comprises the networks responsible for knowing how to do things – holding a pencil, riding a bicycle, speaking, reading a book, planning a trip, writing a narrative. Actions, skills, and plans are highly patterned activities, requiring the frontal brain systems to generate such patterns. Frontal strategic systems are critical for all tasks that involve learning how to act effectively in the world. Working in concert with recognition systems, frontal systems allow us to learn to read, compute, write, solve problems, plan and execute compositions and complete projects (see Jeanerrod, 1997; Fuster, 2002; Stuss and Knight, 2002; Goldberg, 2003).

Strategic systems are important even in learning how to learn. With the help of infrared cameras, Yarbus (1967) studied eye movements as individual subjects examined a picture. He found that the patterns of eye movements differed predictably according to the questions asked by the examiner. For any normal adult, different questions led to very different patterns of eye movements, the outward sign of very different strategies. The capacity to direct one's eyes strategically in this way, like other strategies, is located in the frontal lobes and depends upon experience. Luria (1973), for example, showed that individuals with damage in prefrontal cortex, or normal inexperienced children, do not examine pictures so skillfully or strategically, they do not know how to look at, or learn from, the content of an image.

Similar frontal systems are critical in any kind of information processing, any act of cognition. In reading, for example, competency is not simply in recognizing patterns in visual text, but in knowing how to look for patterns - knowing how to look at the critical features of the letters, knowing how to "sound out" an unfamiliar word, knowing how to look for the antecedent of a pronoun, knowing how to look for an author's point of view. Not surprisingly, frontal cortex lights up in skilled readers (e.g. Shaywitz and Shaywitz, 2004; Sandak *et al*., 2004).

Affective Systems

At the core of the brain (the extended limbic system) lie the networks responsible for emotion and affect. Neither recognizing nor generating patterns per se, these networks determine whether the patterns we perceive matter to us, whether they are important, and help us decide which actions and strategies to pursue. They are not so critical in knowing how to recognize an “A” but in knowing whether an “A” is important (see, for example, Damasio, 1994; Lane and Nadel, 2000; Panksepp, 1998; Ledoux, 2003; Ochsner, Bunge, Gross, Gabrieli, 2002) .

The affective systems, like strategical and recognition systems, are distinctive parts of a distributed system for learning and knowing (Lane and Nadel, 2002; Ledoux, 2003). Clinicians have shown, for example, that amnesiacs may be totally unable to recognize a person or object and yet be able to react appropriately to their affective significance. The patient may be fearful of a doctor who has given them a needle, for example, even though they have no conscious recollection of ever having seen him before.

Under normal circumstance, like viewing a picture, affective preferences are often subtle. Different aspects will strike different individuals as significant or meaningful. Those features will attract more attention, and be remembered better than others. Men and women differ, for example in the details of what they will attend to and remember in complex pictures; each individual has a unique history, which will affect somewhat what is important to us about that picture.

As a result of the effective operation of affective systems, we are able to prioritize goals, develop preferences, build confidence, persist in the face of difficulty, and care about learning. Damage to the limbic system can impair the ability to establish priorities, select what we value or want, focus attention, or prioritize actions. These affective factors are a critical part of any act of cognition.

The Integrated Systems and Cognition

In reality, all three systems contribute an essential kind of knowing that is central to what we call cognition. Successful learning requires all three – recognizing patterns in the environment, adopting successful strategies for acting on those patterns, and knowing what is most important. Learning impairments result from weakness in any of the three. As a simple confirmation, the recent widely circulated NRC report summarized “*three potential stumbling blocks*” in learning to read:

> “*The first obstacle, which arises at the outset of reading acquisition, is difficulty understanding and using the alphabetic principle -- the idea that written spellings systematically represent spoken words. It is hard to comprehend connected text if word recognition is inaccurate of laborious. The second obstacle is a failure to transfer the comprehension skills of spoken language to reading and to acquire new strategies that may be specifically needed for reading. The third obstacle to reading will magnify the first two: the absence or loss of an initial motivation to read or failure to develop a mature appreciation of the rewards of reading.*”

Education, Information, and Universal Design for Learning.

How can modern information technology support individuals who have difficulties in any of the cognitive systems we have described?

For the past 20 years, CAST has sought to harness the power of technology for improving education for individuals with disabilities and their peers – both children and adults. Out of that work has come the framework called Universal Design for Learning (UDL) that is now being widely adopted nationally and promoted by the U.S. Department of Education. Adapted from the concept of universal design in architecture, where structures are designed to accommodate the widest spectrum of users, UDL calls for the design of educational methods and materials that are designed to succeed with the widest range of learners possible, especially including students with disabilities. Within UDL, we have found it helpful to use the three-part framework borrowed from the neurosciences (Meyer and Rose, 1998) as a guide for instructional design. For a longer description of universally designed learning environments and the research around them, see Rose and Dalton (2002) and Rose and Meyer (2002).

Key to universal design for learning is the power of new technologies to provide a flexible foundation – a foundation that is flexible in three ways.

Providing Flexible Means of Representation.

With printed books, there are major limitations in meeting the needs of students with different recognition capabilities. For one thing, there are limited modalities for the display of information - primarily text and images. For another, the content and its display are inextricably linked - information is “fixed,” in a single format, sequence, and display for everyone.

With new digital media designed to support UDL, on the other hand, there is considerable flexibility to meet the needs of individuals with a wide range of cognitive, and especially re-cognitive, abilities. First, there is a wider palette of representation available – not only text but also flexible images, video, sound, networks, even virtual reality. Second, with digital media, the content can be separated from its display. As a result, the content can be generated once and later displayed in a variety of ways – in a different sequence, in a different layout or modality mix, or even with selection of different elements for actual display. Third, each medium remains flexible for many kinds of inter and intra modality transformations, many of which can be generated automatically. Information in text, for example, can be presented simply as text, or as text that “talks” itself aloud, or as text that has hyperlinks to vocabulary definitions (including images) for the ESL reader; or as text with flexible font sizes for the student with visual acuity limitations, text with accompanying background information for the student with cognitive disabilities, etc. All of these simple alternatives remove barriers for some students and provide scaffolds for other apprentices.

There are two advantages to having “multiple representations.” The obvious one is that we can therefore ensure that more children will have access to the meaning in information. There is another, however, that is important in a learning context. With flexible ways of presenting information, the learning environment can be tailored to the child in such a way as to allow students to “focus” their learning - providing opportunities to direct their practice and effort toward more efficacious kinds of skills and strategies – cognitive training wheels.

Providing flexible means of support for action and expression.

The second aspect of cognition, the "strategic systems" for action and expression, are also highly variable among students with cognitive impairments. In a modern digital environment it is possible to embed many ways of supporting such students as they build or implement strategic skills.

What kinds of supports can be embedded? Previous research provides a guide and in the work at CAST we embed the kinds of supports suggested by the literature on cognitive apprenticeships (Collins, Brown and Newman, 1989) and on the cognitive neuroscience of motor action (Jeanerrod, 1997; Goldberg, 2001; Fuster, 2002). Both of these literatures highlight the supports that are typical in an apprenticeship:

1) models of the skill or strategy to be "mirrored" or emulated
2) supported practice with a gradual release of support
3) relevant and timely feedback.

Consider a new digital learning environment called Thinking Reader recently released from Scholastic. It is designed to support students in learning to read strategically. Unlike printed texts, students find the supports and scaffolds they need are embedded in the digital learning environment. When they are learning a new strategy – predicting, summarizing, or visualizing, for example - they will find a virtual agent available, a highly skilled mentor who can demonstrate how to apply the strategy right at that point in the text. That mentor, unlike a real teacher, is always available with the click of a mouse, and is tireless about repetition. When they begin to practice the skill themselves, they find scaffolds available that can be gradually withdrawn as they build fluency. They might find, for example that the text is highlighted for them to help draw attention to information relevant to predicting, or that key points have been presented (along with distractors) to help them understand the step of selecting the most important information in building a summary. These scaffolds can be gradually withdrawn as they gain independence. Finally, as students make early choices to construct predictions, or select items to include in a summary, they get immediate feedback, feedback that is timely and relevant.

The key is that these supports are individualized – they are different for each student according to their needs. This helps to avoid the dual-ended problems that are typical in educational settings – students who are bored because the task is too easy, and students who are terrified or reluctant because the task is too hard.

Providing flexible means of engagement.

It is no surprise that students display considerable variation (both intra- and inter-individual) in the ways in which they can be motivated and engaged in learning. Whether a student is successful in learning new cognitive strategies, or applying the ones they already have mastered, depends to a large extent on whether they are motivated to do so, whether they are engaged by the goals, by the lesson, by the teacher, or whether they are distracted by competing demands or attractions in the classroom (Koskinen, Palmer, Martin, Codling, & Gambrel, 1994).

Students with many kinds of cognitive disabilities are vulnerable affectively - either as a primary aspect of their disability, or as a secondary effect. Students who have learned to expect failure, students who are anxious in a competitive learning environment, students who have weak attentional controls, etc., do not enter the learning environment with the same opportunities to learn as other students.

Printed texts, and particularly textbooks, offer little in the way of options for meeting the challenge of engagement in a diverse classroom. Digital learning environments, however, can be much more differentiated and individualized in the way that they meet the varying needs of students. Primarily, digital environments for learning provide choice - choice in appearance, in level of support, in type of support, in method of response, in content, in speed and distractors. These choices, especially when they are in the hands of students, are keys to whether students feel that the environment “feels right” for them – that it provides the right balance of support and challenge.

The Promise of Universal Design for Learning.

By attending to three simple things – the alternative ways in which information can be presented, the alternative ways in expression can be taught and scaffolded, and the alternative ways in which students can be engaged in learning – we have been able to design learning environments that are pedagogically effective for both regular and special education students, commercially successful, and innovative enough that they are being widely copied. At that, however, we have barely begun.