Session 3

Building on What We Know: Cognitive Processing

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I. Key Questions and Learning Objectives

Key Questions

- How do we process information so that we can use it effectively later?
- How can teachers organize learning to support student understanding?

Learning Objectives

- **Information processing**—Teachers will understand how information is received, organized, and remembered.
- **Associations and connections**—Teachers will become familiar with strategies for helping students to make associations and draw connections among concepts and for enhancing memory and information use.
- **Novices and experts**—Teachers will understand how experts and novices differ in how they solve problems and use knowledge. Teachers will consider how to organize instruction to encourage the development of expert strategies.

II. Session Overview

How do we perceive and understand the world around us? How do we make sense of events and new information? What helps us to remember or forget? How do people think when they are solving problems? And why—and how—does an expert solve a problem more efficiently than a novice? In this session, we explore cognitive processing—the work we do to take in, organize, and make sense of new information. Teachers can assist students as they grapple with new ideas, organize, and communicate what they have learned.

One metaphor for what goes on in the mind of the learner is the set of processes that a computer performs. Learning can be viewed as a matter of encoding and storing information in memory; processing, categorizing, and clustering material; and retrieving this information later to be applied at the appropriate times and situations. To better understand how individuals process information, build knowledge, and develop as problem solvers psychologists collect data from experiments that measure how long it takes for an individual to respond to a prompt; ask learners to think aloud as they solve problems; and examine how novices and experts sort, classify, interpret, and use information. Meanwhile, neuroscientists study how the brain changes biologically as we learn and experience new things.

After an overview of findings about how our experiences affect the brain, we describe how difficulties in perceiving and organizing information can contribute to learning disabilities. We then discuss in more depth how we remember, how we organize what we learn, how these processes can be facilitated in the classroom, and, finally, what cognitive psychologists have taught us about expert problem solvers.

How Does Experience Affect the Brain?

What occurs in the brain as we learn? Studies of animals and human victims of brain injury have demonstrated how experience can affect the brain, and new technologies provide images of the brain in action—showing us which parts of the brain are responsible for specific behaviors and cognitive processes. Brain research has also helped us to understand how people can gain—and regain—skills and abilities through explicit teaching that creates activity in different parts of the brain. Direct connections between brain science and specific teaching practices are not clear at this point; we are only at the beginning of this promising field of research (Bruer, 1997).

In *How People Learn,* Bransford and colleagues (2000) identify three major points about brain development that are important for education:

1. Learning changes the physical structure of the brain,
2. These structural changes alter the functional organization of the brain; in other words, learning organizes and reorganizes the brain, and
3. Different parts of the brain may be ready to learn at different times.

Learning and the Physical Structure of the Brain

As we interact with the world around us, nerve cells, or neurons, send and receive information to and from other nerve cells. Communication between neurons takes place across microscopic gaps, or synapses, and nerve impulses are transmitted neurochemically across these synapses. The neuron integrates the information received from the synapses, which in turn project information to other parts of the body, such as the muscles. This process is the basis of how we think, move, talk, and make sense of the world around us (Bransford, Brown, & Cocking, 2000).

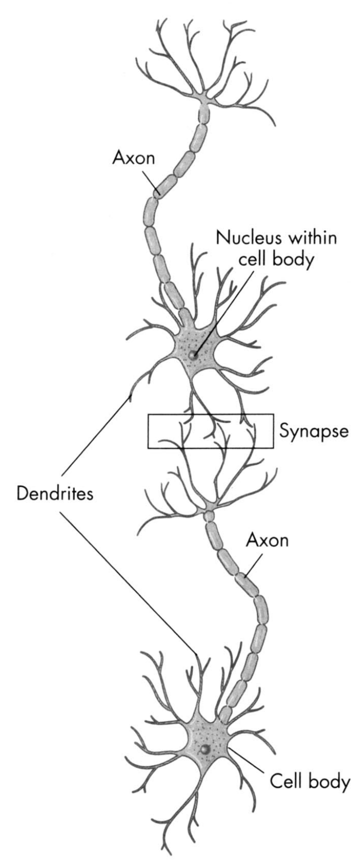

Figure 2. A neuron receives information from other neurons

From Lawry, J. V. & Heller, H. C. (1999). *Human biology: The nervous system* (p. 27). Chicago: Everyday Learning Corporation and The Board of Trustees of the Leland Stanford Junior University. All rights reserved.

II. Session Overview, cont'd.

New connections are added to the brain in two ways: early in life synapses are overproduced, then some are selectively lost (or pruned) because they are not used. Experiencing stimuli in the environment affects the production of new synapses, not only in childhood, but throughout an individual's life. In fact, the quality and amount of information to which a person is exposed is reflected in the structure of the brain. For example, when individuals are deprived of certain visual stimuli at an early age, the ability to process visual information is permanently hampered. On the other hand, when individuals experience brain damage, from head injury or stroke, for example, their capacities can often be reclaimed through therapy that redevelops the connections in the brain. Neuroscientists have also found that learning specific tasks brings about changes in the areas of the brain specific to those tasks. For instance, in the nervous system of deaf individuals, pathways typically used for hearing have been adapted to process the visual information in sign language (Blakemore, 1977; Friedman & Cocking, 1986, both cited in Bransford et al., 2000, p. 123).

More complex cognitive processing occurs in the cerebral cortex—the blanket of cells that covers the brain and is divided into lobes, each of which performs many different functions. Scientists have learned how different parts of the brain are linked to different functions through studies of brain-damaged individuals. For example, by studying victims of stroke and accidents, scientists have learned that each hemisphere controls motor and sensory functions on the opposite side of the body, and that the left hemisphere of the brain is dominant for language, whereas the right hemisphere is dominant for visual-spatial functions. This finding has led to the notion of "brain-based" education (e.g., to develop the left hemisphere, teachers should focus on oral and written language, to develop the right hemisphere teachers should encourage their students to use images). However, a closer look at the research reveals that most complex tasks involve *both* hemispheres (Bruer, 1999).

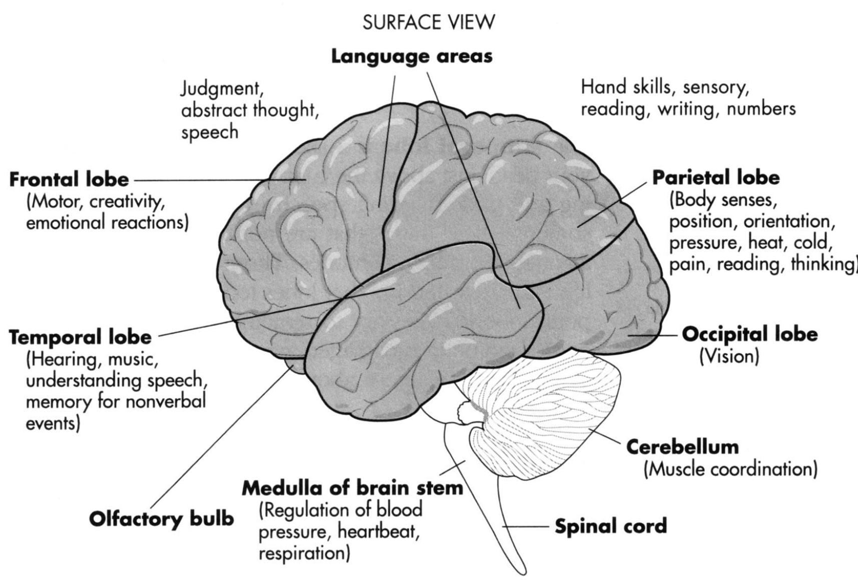

Figure 3. The parts of the brain and their functions

From Lawry, J. V. & Heller, H. C. (1999). *Human biology: The nervous system* (p. 20). Chicago: Everyday Learning Corporation and The Board of Trustees of the Leland Stanford Junior University.

It is a common misconception that individuals' intelligence and brain development are entirely predetermined by biology. Education and experience do develop the brain. Physical and mental activity of various kinds help people develop their capacity to learn, and what teachers do can affect brain development by engaging students in activities that help them develop their capacities. This can range from the kind of neurological programming that occurs when musicians practice certain patterns of physical movement tied to symbol systems (musical notes) and when readers practice letter-sound correspondences and learn comprehension strategies. Learning abilities can be developed by access to an environment that stimulates and uses the brain.

II. Session Overview, cont'd.

One of the most commonly cited studies on the effect of the environment on brain development is the work of William Greenough and his colleagues (1987), who studied rats placed in various environments and the resulting effects on synapse formation in the rats' brains. They compared the brains of rats raised in "complex environments," containing toys and obstacles, with those housed individually or in small cages without toys. They found that rats raised in complex environments performed better on learning tasks, liked learning to run mazes, and had 20–25% more synapses per neuron in the visual cortex. This work suggests that brain development is "experience-dependent," allowing animals to acquire knowledge that is specific to their own environments. These experiments suggest that "rich environments" include those that provide numerous opportunities for social interaction, direct physical contact with the environment, and a changing set of objects for play and exploration (Rosenzweig & Bennett, 1978, cited in Bransford et al., 2000, p. 119). Similarly, rich classroom environments provide interactions with others in the classroom and community, hands-on experiences with the physical world, and frequent, informative feedback on what students are doing and thinking.

New advances in technology have also informed scientists' understanding of how humans process information. In emerging brain research, imaging technologies are helping scientists localize areas of brain activity that underlie the cognitive components of a task; with imaging, areas of the brain are shown to "light up" under varying conditions. For example, the physical activity of the brain during reading differs for dyslexics and non-dyslexics. Some researchers have relied on these images to improve understanding of how to teach dyslexic students (Shaywitz, 1996; Tallal et al., 1996). Cognitive psychologists—those who study how we learn by conducting human experiments and observations—can help us to bridge understandings in neuroscience with implications for the classroom. In the following sections, we discuss in more depth what has been learned about how we processes information and how we build knowledge through our experiences.

How Do We Perceive and Make Sense of the World Around Us?

We are constantly bombarded with stimuli and information, not all of which can be attended to at once. What is perceived and processed in the brain depends on several features of the stimulus as well as of the perceiver. Critical are:

- What captures our attention—the visual, auditory, or other attributes of the stimulus that cause us to pay attention. As advertisers well understand, these can be manipulated to heighten the probability that we will attend to the phenomenon;
- How we selectively filter out aspects of the information that are unfamiliar or uncategorizable to us or that do not mesh with our expectations; and
- How we organize the information in our brain, connecting it through associations with other things we know (Levine, 2002).

People more readily process information that connects to things that are already familiar to them. They will even change the information (i.e., recall something incorrectly) by interpreting it so that it becomes familiar and thus understandable to them (e.g., Sulin & Dooling, 1974, cited in Anderson, 1995). Encoding information using multiple sensory pathways can help it to be taken in and recalled more effectively; for example, by learning something in rhyme or musical form (e.g., learning the ABCs to music), by learning something both aurally and visually, or by learning something both aurally and kinesthetically (e.g., memorizing a phone number by dialing it repeatedly so that it is remembered kinesthetically as well). Finally, people are more likely to remember things that have been highlighted for their attention and located in relation to a broader cognitive map (Sprinthall, Sprinthall, & Oja, 1998). As we discuss in the sections below, teachers often use "advance organizers" in presenting information so that students will know what to look for and what to focus on—and therefore be more likely to perceive and process the information.

II. Session Overview, cont'd.

Individuals process information differently in the brain. For example, people learn through different pathways and modalities—visual, aural, kinesthetic—and with different kinds of representations. [See Session 4, Multiple Intelligences, for further discussion of learning differences.] These differences pose a challenge for teachers, requiring that they represent ideas and information in ways that allow for different kinds of processing and figure out what will allow certain students to process information most effectively. For instance, a student who is not strong verbally might be able to draw a map or picture of what she is thinking and label it as a tool that helps her explore and refine her ideas in conversation.

Many researchers attribute specific learning difficulties to problems that occur when the brain processes language and other visual, auditory, and kinesthetic information. Although not all causes are known, processing differences and difficulties can be attributed to a number of biological causes, including heredity (for example, dyslexia tends to be hereditary), as well as trauma at birth, malnutrition, and maternal drug use. Certain childhood illnesses or drug treatments can also affect brain function. For these reasons, learning disabilities are more frequently found in children who have experienced poor prenatal care. Some temporary difficulties in brain function are caused by biological factors. For example, a large number of children, especially those living in urban areas, are asthmatic; many take medications for their allergies or asthma that influence the brain, often making a child groggy or hyperactive, and that can significantly affect a student's experience in the classroom. However, it is usually difficult to point to a single cause for a learning disability.

Learning disabilities take different forms—they are related to language comprehension and production, motor skills, social skills, and attention, for instance. Disorders specifically related to information processing are typically seen when children have difficulty making sense of what they see and hear. For example, children with *visual* perceptual problems may orient differently and thus have difficulty noticing differences between some letters (like *b* and *p*) and numbers (like *6* and *9*). They also have trouble distinguishing a shape or number from its background (e.g., in a phone book or newspaper). They may have trouble remembering symbol patterns they have seen (thus complicating spelling), describing a place they have visited, or reproducing visual symbols. Children with *auditory* perceptual problems have trouble distinguishing the separate sounds in words, following oral directions, and remembering things they have heard (*LD Basics*. Retrieved from http://www.ncld.org).

In addition, children who have difficulty paying attention and are easily distracted cannot easily organize the information coming in—a central aspect of cognitive processing. These children often have trouble making sense of their environments. Smith describes the confusion they face every day:

> Have you ever tried to find your way in a strange city, following someone's directions that referred you to streets you hadn't seen—and with the noise of the traffic, screaming sirens, and people shouting all around you, making it harder to understand?
>
> When you want to understand something and you can't filter out what's important, what's meaningful, from what isn't, you probably feel overwhelmed, dumb, threatened, perhaps helpless, and then angry. It is frustrating to be unable to separate out the essential parts and put them together in a meaningful whole. You can't make sense of your environment in this way.
>
> For learning disabled children the ability to organize has been somehow been short-circuited and normal learning cannot follow (Smith, 1995, pp. 15-16).

Dr. Mel Levine, a pediatrician at the University of North Carolina, has developed ways for teachers to carefully and systematically assess the needs and strengths of each student, by developing a *multidimensional* profile (as opposed to a single label):

> We must look carefully at each of the functions of the brain that affects the ways a student learns as well as performs in school—functions such as memory, language, and attention, the ability to organize information, neuromotor functions such as fine and gross motor skills or physical coordination, social cognition—the ability to understand as well as have appropriate and successful social interactions, and higher order cognition—being able to solve problems, think critically, or otherwise reason about oneself and the world (*Our perspective: The approach*. Retrieved from http://www.alkindsofminds.org).

II. Session Overview, cont'd.

It is important for teachers to have skills and tools for observing and cataloging the kinds of tasks with which students seem to have difficulty, as well as those with which they have greater success, as a guide to curriculum planning and instructional adaptations. The National Center for Learning Disabilities provides a checklist on its Web site (http://www.ncld.org) for the common warning signs of learning disabilities at different ages. For instance, in elementary school, teachers should pay attention to children who have trouble learning new vocabulary, speaking in full sentences, understanding the rules of conversation, retelling stories, or remembering newly learned information. Teachers of adolescents should pay attention to students who have trouble staying organized, understanding what they read, getting along with others, expressing thoughts orally or in writing, and following directions. These are just a few examples of behaviors that may be indicators of a learning disability. Special education teachers can be valuable resources for the kinds of assessment tools—both formal and informal—a teacher might use in her classroom. As we discuss later, understanding how processing occurs—both for these children and others—can help teachers develop more effective teaching strategies. In the next sections, we discuss more specifically the cognitive processes involved in remembering, organizing information, and solving problems.

How Do We Remember?

For learning to occur, facts, concepts, and ideas must be stored; connected to other facts, concepts, and ideas; and built upon. Cognitive theorists have studied the nature of memory to determine how and under what conditions people retain or forget information. They distinguish between "working memory"—information that is temporarily stored, manipulated, and later forgotten—and "long-term memory"—information that can be recalled for an unlimited time. Researchers have found that working memory capacity is limited to about seven (plus or minus two) chunks of information (Miller, 1956, cited in Sprinthall et al., 1998, p. 306). For example, information such as a telephone number that you just looked up is stored in working memory and forgotten unless this number is rehearsed or encoded in long-term memory. Forgetting does serve a purpose: If we did not forget, our minds would become overwhelmed with information.

In theory, we can store unlimited amounts of information in long-term memory, but we cannot always access this information because of the way our brains search for it (Gage & Berliner, 1998). We also may have trouble retrieving information from long-term memory because some new information interferes with this process (e.g., Watkins, 1975, cited in Medin & Ross, 1992, p. 197). For example, as you learn your second foreign language, vocabulary and grammar from the first foreign language you learned may interfere with what you are learning.

How can memory be enhanced? Researchers have found that information is stored in several forms—visual, verbal, and by its meaning (Gage & Berliner, 1998). When physical, auditory, and visual stimuli are combined with symbolic materials like language or numbers, the ability to retrieve information is likely to be improved. For example, teaching a foreign language with physical responses and sensory experiences will increase the likelihood of the learner retaining this new information (Cohen, 1989, cited in Gage & Berliner, 1998, p. 264). Research also demonstrates that when people are asked to remember a series of events or list of words, they will do better at recalling them if they create categories or meaningful connections among them, and if they "chunk" this information into smaller groupings (Lichtenstein & Brewer, 1980; Roediger, 1997; both cited in Bransford et al., 2000, p. 124). Students might more easily remember the American presidents in order if they make up a story that links their names; students might remember the animals living in a rain forest by clustering them according to which category they belong to—carnivore, herbivore, or omnivore. Research on memory suggests that teachers should provide multiple modes of presenting information, offer opportunities to make meaningful connections among concepts, and help to structure categories of information.

There are several other strategies for enhancing the retrieval of learned material, including overlearning, learning with understanding, and relating material to an organized knowledge base (Sprinthall et al., 1998). *Overlearning* is simply the process of continuing to study and practice material after it has been mastered; the more time spent on a subject and the more actual use of its ideas and skills mean better retention and skill development. When something has been learned to a point where information retrieval (or the performance a skill requires) is automatic or requires little conscious effort, researchers say that the learner has achieved "automaticity" with respect to that information or skill, whether it is playing scales on a musical instrument, driving a car, using an arithmetic fact, or calling up a literary term. When this occurs, it frees other aspects of the learner's consciousness to grapple with new information or more complex problem solving.

Reproducing something automatically, however, does not mean that a learner understands the information or can apply it appropriately when needed for a novel problem. For example, the fact that many people can recite $e=mc^2$ does not mean that they understand Einstein's theory of relativity well enough to explain it or use it. *Learning with understanding* has occurred when students can successfully apply what they have learned in a new situation (Gardner, 1991). This kind of learning is facilitated when learners have a conceptual framework or map that organizes categories of information and shows the relationship among concepts, as opposed to an unrelated body of facts. [See Session 10, The Structure of the Disciplines.] Students are more likely to learn information quickly and efficiently when provided with ways to organize it. Each new well-learned concept—particularly if it is a central idea that is understood in connection to other central ideas—provides a kind of anchor that facilitates the acquisition of new information. For example, if a student understands the concept of supply and demand and how it relates to ideas like price and production, she can learn and organize many other pieces of economic information in relation to these concepts. In addition, learning for understanding requires applying knowledge in performance situations, by explaining a concept to others, using it in another context, researching it deeply, or representing it in a new way, for instance (Wiske, 1998).

To develop transferable understanding or proficiency, people have to put skills to use in an integrated fashion, rather than merely recalling information in disconnected bits. As a consequence, theorists from John Dewey to Howard Gardner have advocated the use of project methods that enable students to study things deeply and to use what they know. Researchers have found that the more learning is meaningful to the individual, the greater the likelihood of its acquisition, retrieval, and later use.

The acquisition of knowledge is also improved when new knowledge *builds on an existing organized knowledge base:*

> Just as new motor skills are improved by positive transfer (learning to ride a bike aids in learning to ride a motorcycle), so too are more cognitively based skills. Concepts build on facts, and *concepts build on concepts.* Knowing how to add, subtract, multiply, and divide is obviously helpful to the student taking a course in algebra. Having taken algebra, in turn, makes a course in physics more understandable (Sprinthall et al., 1998, p. 318).

When the curriculum is organized in a manner that allows new material to build on earlier learning, and when new material is tied to what students already know, teaching effectiveness is increased (White & Gagne, 1976, cited in Sprinthall et al., 1998, p. 318). For instance, an elementary school teacher who is just beginning a unit on fire stations might ask students to brainstorm what they already know about firefighting and map out the class's collective knowledge in a whole-class discussion; she can use this base both to help students organize their collective knowledge and to make decisions about how to structure the instruction that follows. Similarly, an environmental science teacher might give his students a preassessment about the types and causes of pollution to get a snapshot of their current understandings. Building on prior knowledge also means identifying and filling gaps in students' prerequisite knowledge base to pave the way for new information to be learned, remembered, and understood.

How Do We Organize and Build Knowledge?

Perceiving and remembering are influenced by our prior experience, our expectations for a given situation, and our ability to make connections among ideas. The importance of a meaningful *context* for building knowledge cannot be underestimated. Students will process information, make connections, and retrieve what they have learned more effectively if the learning has meaning to them and they can apply what they are learning.

Cognition is cultural. The ways people categorize ideas, build knowledge, and reason are all influenced by the values and common activities of their culture. This is true of ways of thinking and working, as well as ways of communicating and behaving [See Session 6, Culture and Learning]. Students' different experiences will give them familiarity with different ideas, which will influence how well they can connect with the various examples or representations teachers might choose to illustrate a concept. This is also true of tests. For example, one researcher found that children in southern California were not able to answer questions on a national test (created in Minnesota) that asked about sledding. Students bring to school with them many kinds of experience bases; helping them build meaningful associations is partly a matter of understanding their cultural contexts and using stories, examples, connections, and illustrations that will enable them to make sense of things.

Making Connections

The simplest kind of association is developing a connection between two ideas. For instance, if a teacher wanted her students to remember the products each state produces, she might have them draw a picture of that product in each region on a map of the United States as a visual reminder. Learning relies on building these simple associations as well as developing understandings about more complex relationships.

The way a set of new information is presented to students makes a difference in their learning and their ability to make new connections. For many purposes, presenting material in a tightly organized fashion, with "advance organizers," or a foreshadowing of the general concepts that describe how ideas are grouped or structured, can help students better learn the material that follows (Ausubel, 1968; Ausubel, 1978; both cited in Gage & Berliner, 1998, p. 289). By providing a general preview, the teacher can alert students about what to pay attention to and how to organize it, thus making the material easier to learn and retrieve, while providing a kind of mental scaffolding for what follows. The literature teacher who introduces a number of themes before students begin a novel, the history teacher who outlines the major trends in a time period that will be studied, and a science teacher who highlights the parts of a cell that will be studied, are providing advance organizers for their students. In a similar manner, the key questions posed at the beginning of each session in this course guide are intended to prepare the reader for what is to come.

Sometimes it is helpful to organize material in an inductive manner, beginning with simple, concrete ideas and later advancing to more complex, abstract concepts and principles (Gagne, 1985, cited in Gage & Berliner, 1998, p. 290). This is particularly the case when it is possible and desirable to start with a hands-on example. The geometry teacher who begins with students measuring the area of different shapes, and later helps students figure out the patterns and the formulas for more efficient problem solving, is using this inductive approach. Clearly, there are advantages and disadvantages to each approach and times when one or the other is likely to be more useful for the teacher's purposes. What they have in common is that each is a purposeful way of ordering and drawing connections between ideas in ways that are made clear to the learners.

Developing Conceptual Knowledge

Throughout their lives, individuals develop more complex associations among words, concepts, and ideas. Cognitive psychologists call these "schemas," or general knowledge structures used for understanding and memory storage. Schemas consist of information, in an abstract form, of the associations we have with a word, concept, or idea, and they in turn connect with other schemas. For instance, the schema for "student" intersects with the schemas for schooling, teaching, and studying (Gage & Berliner, 1998). Mentioning this one word calls up a related list of words, images, and ideas linked to the original concept. One can consciously develop well-organized schemas as a way to make learning more efficient; for example, when one learns the Latin roots of words to make the understanding of vocabulary more systematic.

Schemas serve as place-holders, or organizers, of our life experiences. They help us understand how knowledge fits together and assist us in generating expectations about what is likely to happen; they also help us understand later events and notice if something unusual is happening (Rumelhart, 1980; Schank, 1982, both cited in Medin & Ross, 1992, p. 351). For instance, a person might have a schema for how one is served in a fast-food restaurant, but may not possess a schema for ordering in a sit-down restaurant (Medin & Ross, 1992). Similarly, a student might have a schema for "revolution," but may not have a developed understanding of the forces and factors at play in a military coup.

The schemas one brings to a learning experience—a person's background knowledge—influence what is learned and what is retrieved. Part of the teacher's role is to develop and enrich students' existing schemas and the ways their minds organize information. Teachers can do this by activating prior knowledge before introducing concepts, by comparing and contrasting new ideas or concepts to those for which students already have well-developed schemas, and by organizing discussions and demonstrations about new concepts to help students develop useful schemas. For instance, a drama teacher might have students discuss their understandings of tragedy before launching into reading *Macbeth* (activating prior knowledge), lead a discussion to compare and contrast the genres of tragedy and comedy (comparing schemas), or help students to identify some of the central features of a tragedy while acting out the play (organizing a demonstration to develop a schema).

As we develop understandings of concepts, we create new associations among ideas. One way to make these new associations visible to teachers and students is by creating a visual representation or diagram of the underlying features and structures of a concept. Visualization is one of the strategies that humans have acquired to overcome their cognitive processing limitations. We can only keep so much in memory at once. As we write or draw a diagram, we can start to look at part-to-whole relationships in ways that save us from having to remember a large amount of information. In a single glance, a diagram can show the relation between the parts of the machine to the machine itself. Because they are visual and show how ideas relate to one another, visual representations can help the learner comprehend, store, and recall information (Gage & Berliner, 1998). For example, a teacher might introduce a unit on mammals with a tree diagram of the features of warm-blooded animals, as illustrated in the following "concept map":

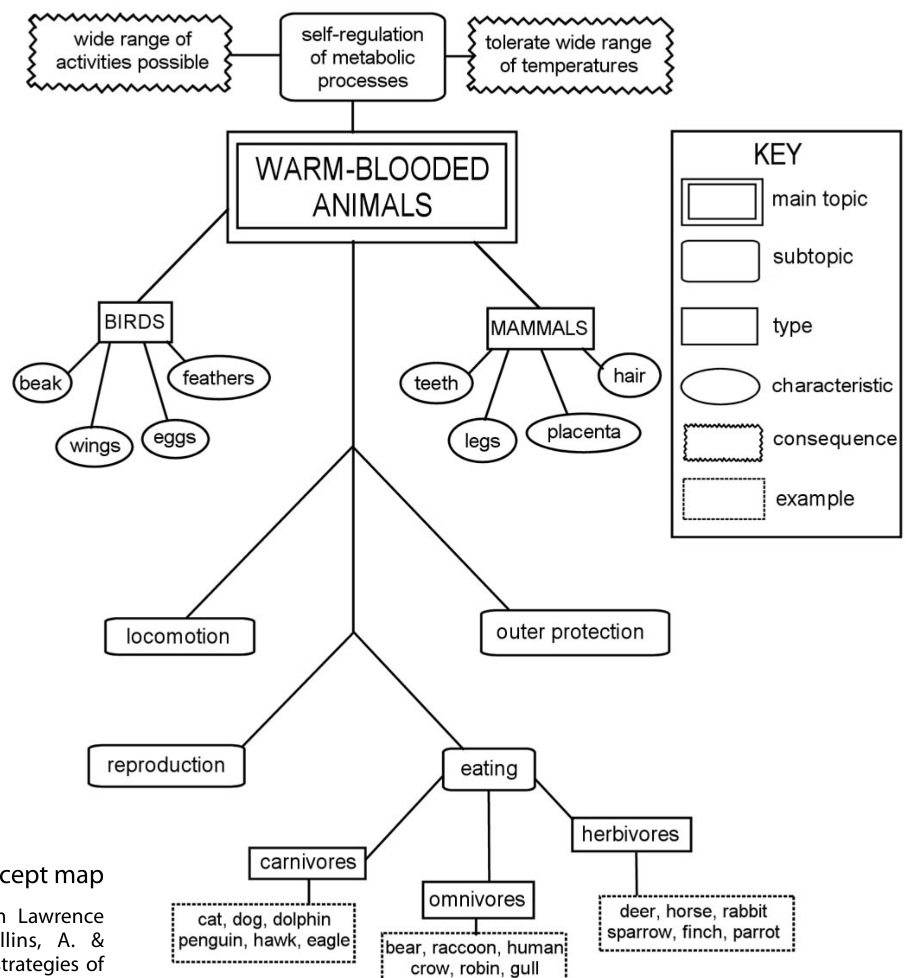

Figure 4. Example of a concept map

Reprinted with permission from Lawrence Erlbaum Associates. From Collins, A. & Stevens, A. L. (1982). Goals and strategies of inquiry teachers. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2). New York: Lawrence Erlbaum Associates.

II. Session Overview, cont'd.

Asking students to map their own knowledge about a concept or set of relationships can help them to organize their thinking and it can also provide important information about their understandings and misconceptions. Asking students to make their thinking visible is useful to the teacher in several ways: it provides the opportunity to introduce more typical forms of representing those ideas visually, it provides information about useful insights or confusions in the way that the child is thinking, and it provides a set of models for students and their peers that can provoke exploration of different ways of seeing and thinking about things.

Developing Explanations

Another way we build knowledge is through the construction of explanations about different phenomena. Individuals carry around "mental models," or explanations, in their heads for why things happen. These have been described as "constructed working models of the world used in the service of understanding" (Medin & Ross, 1992, p. 359). Mental models can be used to describe the knowledge one has about how something works or to explain a set of relationships. For example, children's conceptions of how a fax machine works can be diagrammed, including how information is translated, communicated, and generated in a different location. Similarly, children can develop mental models about planetary movements that cause seasons to occur, the relationships among different mathematical operations, or the causes and effects of the Great Depression.

The following "causal map" illustrates one student's mental model for the factors and steps involved in rice growing (Collins & Stevens, 1982, p. 66).

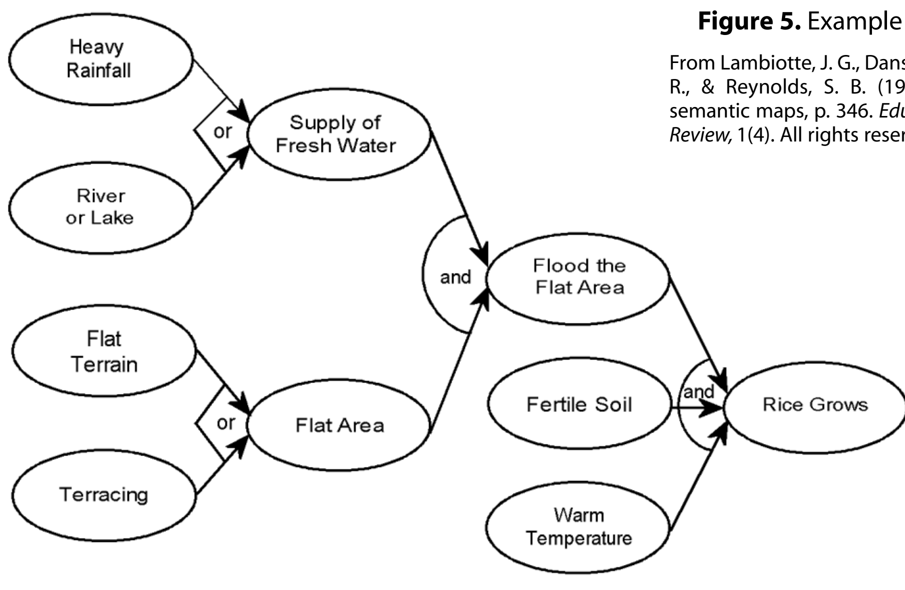

Figure 5. Example of a causal map

From Lambiotte, J. G., Dansereau, D. F, Cross, D. R., & Reynolds, S. B. (1989). Multirelational semantic maps, p. 346. *Educational Psychology Review,* 1(4).

Mental models may come from students' intuitive theories—like theories of motion or theories of evolution—or they can be provided as a form of instruction by teachers or textbooks. This instruction may be well or poorly understood. The mental models students develop may be more or less accurate and, as a consequence, more or less helpful for developing true understanding. They can even get in the way of understanding. It is still not clear how people's intuitive theories, or mental models, are acquired and changed, but teachers can draw on or confront students' mental models to address misconceptions and provide students with new models to help explain phenomena. Representations of these mental models can be shared with teachers in journals or logs, or used for pre- or post-assessments.

We make simple associations, develop existing schemas, and generate new explanations for phenomena every day. However, we all process information on the basis of what we know, and all of us have different mental maps; if we do not have something to "hook" new information to, we will not be able to include it in our current mental map, understand it, and work with it. Part of the teacher's job is to build on students' current understandings, provide these hooks, and make new ways of thinking about ideas and relationships *visible.* Organizers such as concept maps, analogies, charts, and tables can help teachers create or reveal the underlying connections between and among ideas and can help students to organize their thinking about new topics. As we have seen, organizing your thoughts involves the ability to sort information (classify, categorize, and label), decide which information is appropriate (what belongs and what is missing), recognize how parts make up a whole, and recognize sequences (e.g., beginning, middle, and end) (Smith, 1995). There are several ways teachers can support all children in organizing their learning, including those who experience challenges in cognitive processing. Teachers can:

1. Structure the learning process
    - Establish routines and procedures
    - Simplify directions, cluster and sequence activities
    - Demonstrate an idealized version of the task to be performed
    - Organize and guide practice efforts
2. Organize information and help students to organize what they are learning
    - Provide categories and labels for organizing information
    - Provide alternative representations (e.g., pictures, metaphors, and analogies), use concrete examples of abstract ideas
    - Draw attention to critical features or ideas
    - Use a multisensory approach to teaching: Provide opportunities for students to process and organize information through different pathways for input and output (e.g., aural, visual, kinesthetic, linguistic, mathematical, spatial, musical, social, role play, and simulation)
    - Encourage students to organize information by thinking out loud, talking with others, visualizing concepts, and making connections to personal experiences
3. Identify students' strengths, preferences, prior knowledge, and experiences
    - Identify and build on students' preferences for information processing (e.g., receiving instructions orally or in writing, expressing oneself through drawing or writing)
    - Make connections to their prior knowledge and experiences
    - Use culturally familiar strategies for learning and responding (e.g., question types, narrative styles)
    - Use culturally familiar examples

Knowledge in Practice: How Do Experts Solve Problems?

One of the ways researchers have discovered differences in cognitive processing is by comparing experts and novices as they solve problems in specific domains. Asking an expert and novice to solve the same problem reveals important differences in information processing, the organization of knowledge, and reasoning. As we discuss below, expert knowledge tends to be organized around related *core concepts* in a subject area, experts notice *meaningful patterns* when they are solving problems, and experts tend to *monitor* their work and check their solutions more frequently than novices. Teachers can coach students in these expert strategies as they help them develop skills and understanding in different areas.

II. Session Overview, cont'd.

Researchers have found that expert knowledge tends to be organized around *core concepts* or big ideas that guide their thinking and encompass a large number of interrelated facts or patterns. [See Session 10, The Structure of the Disciplines.] By contrast, novices' knowledge tends to be organized around relatively unrelated facts and formulas. For example, chess masters can recognize and recall many chess pieces in a strategic configuration; electronics technicians can reproduce large portions of circuit diagrams after only a few seconds of viewing; expert teachers notice and can interpret many more elements of a classroom situation than do novices (Bransford et al., 2000). Experts have "more conceptual chunks in memory, more relations or features defining each chunk, more interrelations among the chunks, and efficient methods for retrieving related chunks and procedures for applying these informational units in problem-solving contexts (Chi, Feltovich, & Glaser, 1981)" (Bransford et al., 2000, p. 38). The quality of these problem-solving processes depends on the problem solver's subject matter knowledge as well as his strategic knowledge. These findings suggest that curricula should be organized in ways that lead to conceptual understanding, by leading students to organize knowledge meaningfully, rather than through a superficial coverage of facts and skills. Teachers can help students become more expert by helping them develop a better understanding of core concepts within a subject area and relationships among them.

Conceptual understanding—that is, an understanding of the underlying ideas and relationships in a domain—influences what the learner pays attention to, what is remembered, and what kinds of errors are made in learning something new. One way conceptual understanding can be encouraged is by confronting common misconceptions and misunderstandings, and then addressing them. For example, in this session's video we see teacher Sandie Gilliam highlighting and addressing students' misconceptions about how to graph information.

The value of confronting misconceptions is illustrated in a study by sixth-grade teacher Kathleen Roth. Roth documented her students' understandings and misconceptions as they worked with the notion of how plants obtain food (Roth, 1986, cited in Gagne, Yekovich, & Yekovich, 1993, p. 411). She discovered that many students had strong beliefs that plants get their food from the soil, as opposed to creating it in their leaves. To address this misconception, she wrote a text that first asked students to consider their prior knowledge about plants and food, and then presented experimental evidence and other information in order to challenge the idea that plants get food from the soil. Students who read this experimental text showed that they understood most of the concepts on the post-test, in contrast with a group who had studied a more traditional text and demonstrated less conceptual understanding. This is one example of how uncovering and addressing students' misconceptions can be effective in developing students' understanding of key ideas in a discipline.

Experts not only have acquired a great deal of content knowledge, but they also understand how to determine the contexts in which particular kinds of knowledge are useful (Simon, 1980; Glaser, 1992; both cited in Bransford et al., 2000, p. 43). They can retrieve important aspects of their knowledge when appropriate and needed, which is often called "effortless processing" (Schneider & Shiffrin, 1977, cited in Bransford et al., 2000). This does not necessarily mean that experts always process information faster, but it does mean that over time they become fluent at recognizing problem types and putting into practice a range of solutions that respond to these types (Glaser & Chi, 1988). An important difference between novices and experts in any of the fields in which they have been studied—from chess to writing to mechanics to bartending—is that experts tend to see the world differently. They see patterns in situations that indicate typical problems. For instance, when an expert teacher views a classroom with 30 students all vying for attention, in the context of some complex piece of teaching, he will see different opportunities and potential problems than a novice teacher does. Like a chess player, he is imagining different scenarios: If I respond in this way to that child's question, what will happen to this other group? If I follow this path of discussion, what are the costs and benefits?

Experts also use a number of different strategies to solve a problem. Expert mathematicians do not rely on equations alone; they also write, draw diagrams, use computer programs, and create graphs and data tables. Whereas novices may perceive problem solving as memorizing, recalling information, and manipulating equations, experts recall appropriate laws and principles, based on the patterns they see (Chi et al., 1981; Larkin, 1981; Larkin, 1983; all cited in Bransford et al., 2000, p. 37, 38). Helping students become expert in mathematical problem solving means first identifying the expert skills and concepts, and then determining how to support the students in acquiring those skills and concepts.

Another way to help students become aware of patterns and principles is by teaching them how to categorize ideas or types of problems. In this session's video, for instance, we see teacher Fe MacLean helping her students create categories based on the characteristics of animals. Building students' schemas for how ideas or problems are similar can help foster better understanding and more efficient problem solving. One researcher found that the manner in which seventh graders grouped types of mathematical word problems was directly related to their ability to solve the problems (Silver, 1981, cited in Gagne et al., 1993, p. 359). These kinds of studies suggest that part of the work of instruction is to provide students with opportunities not just to solve problems, but also to *classify* them, thereby focusing their attention on the schemas they can use to solve them, rather than just the solution procedures.

Finally, experts tend to check their solutions to problems and *monitor* their own work more frequently and with better results than novices. Novices often become distracted by apparently important, but often irrelevant, aspects of a problem (Bransford et al., 2000). Experts manage their mental work, they think about how much time they have and how much time they need, they are aware of what they know and do not know, they focus their attention to attend to the most important issues, and they know when to shift course. Teachers can explicitly teach expert strategies for evaluating, solving, and checking problems.

The writing process can also be seen as a problem to be solved: The writer must develop an understanding of the task at hand (a "problem representation"), she must monitor her work as she writes and revises to make sure she is accomplishing her goals, and she must put into practice knowledge about communication strategies, as well as conventions, techniques, and procedures. As she becomes more expert, the evolving writer will learn to think strategically about her work:

> Novice writers work on surface features, using word and punctuation deletion and addition as important strategies; experienced writers conceptualize the task as a wholistic enterprise that may require elaborating the treatment of a point, insuring the effectiveness of argument structure, and estimating the utility of shifts in voice as well as checking grammar and punctuation (Glaser, 1992, p. 70).

Over time, certain aspects of problem solving become automatic—just as certain aspects of driving a car or reading become automatic with practice. One way to help students learn these skills is to give them problems that require them to practice choosing the appropriate concepts, formulas, and strategies for solving them. Novices can also benefit from being exposed to expert approaches to problem solving and expert strategies for self-monitoring. Teachers can model expert thinking both by demonstration and questioning so that students can understand what considerations are important and what processes of problem solving are likely to be successful. [See Session 8, Cognitive Apprenticeship, for further discussion of modeling expert processes, guiding practice efforts, and providing feedback.]

Glaser (1992) suggests that teachers consider four strategies in designing experiences for students that will enable them to develop competence in solving problems: 1) provide increasingly complex opportunities to *practice* solving problems; 2) create opportunities for *self-monitoring;* 3) encourage *principled performance* (e.g., help students link their schemas for problem types to specific problem-solving strategies); and 4) consider the *social context* of learning. When students work collaboratively to solve problems, their conceptual understanding is enhanced, and their thinking becomes more explicit regarding the processes they are using. A social context where students have opportunities to share tasks, receive guidance from others, and perform for an audience can make complex tasks more manageable.

Conclusion

How can studies of brain development and cognitive processing help us think about teaching and learning? Processing and making sense of information depends on a number of factors, including the nature of the learning environment, individual differences in perception and understanding, and the manner in which new information is presented. In terms of the learning environment, we can ask, "How can teachers create rich, stimulating environments for learning?" Such an environment calls up images of the colorful setting and buzzing activity of the hands-on preschool classroom. Consider how the classroom environment at every level of schooling might

II. Session Overview, cont'd.

provide provocative materials and opportunities for hands-on exploration. In terms of learners' differences, we can ask, "How might teachers learn about students' differences, difficulties, and preferences for processing information—in perceiving, remembering, and communicating, for example?" Consider how teachers might use the information they gather about their students to guide instruction. What are the different ways of accessing students' conceptual understandings and explanations? How might the way teachers present new information help to develop these understandings? And finally, "How can we help students learn expert skills and strategies to enhance their abilities?" Attending to cognitive processing means taking into account and tapping into the often-invisible ways we develop knowledge, solve problems, and make sense of our worlds.

III. Additional Session Readings

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IV. Session Activities

Getting Started

Answer one of the following questions in a free-write, pair-share, or small-group discussion.

1. How do you remember what you learn? Describe some of the strategies you've used in the past to help yourself remember information.

OR

2. Think about and describe some of the ways you help your students to remember—and to organize in their minds—key facts, concepts, and ideas.

To the Facilitator: These activities can be used as session warm-ups or as activities that occur after video viewing.

Discussion of Session Readings

To the Facilitator: You may want to select questions from the Other Learning Activities and Assessments section to launch a discussion of the session readings. The questions used for the Checking for Understanding activities may be a particularly helpful resource.

Session Video

This video demonstrates how teachers can assist students as they process new information, draw connections, and represent ideas in different ways. When we introduce new material in the classroom, each student makes sense of it in his or her own way. One may remember a past experience and then place the new material in a similar category. Another may hear only a string of words that make no sense until a "hands-on" experience is made available. A third may unintentionally misunderstand the information to make it fit better with what he already knows. All of this is part of cognitive processing. In this video we see how teachers can help students make sense of what they learn by connecting new ideas to what students already know, presenting ideas in different ways, using vivid representations, organizing information by making big ideas and relationships explicit, and making sure students have a chance to work with and apply the information.

Background on Teachers

Fe MacLean is a first grade-teacher at Paddock Elementary School in the small, culturally diverse town of Milan, Michigan. Ms. MacLean, with 36 years of teaching experience, holds a bachelor's degree in elementary education from the Philippine Normal College, and a master's degree in learning and cognitive development from the University of Michigan. She is a National Board-certified teacher and a winner of the Presidential Award for Excellence in Mathematics and Science Teaching (2000). In 2000, she received a Fulbright Memorial Award for Teacher Study in Japan.

In the first video segment, we see Ms. MacLean helping her students develop new ideas connected to prior understandings. She also helps them to organize what they are learning with the aid of graphic organizers. Ms. MacLean uses activities like an animal habitat project and museum trip to provide applications and make her students' learning come alive. As they classify animals and create visual representations of their habitats, they process the information more deeply and draw more connections. By having them talk, write, and draw about their experiences, MacLean encourages her students to articulate as well as visualize their thinking.

Sandie Gilliam is a ninth- to 12th-grade mathematics teacher at San Lorenzo Valley High School in Felton, California. Ms. Gilliam has 27 years of teaching experience and received her bachelor's degree in mathematics from San Jose State University, California. She is a National Board-certified teacher and recipient of the 2000 Presidential Award for Excellence in Mathematics Teaching. As a past instructor with the California Mathematics Project and contributor to the Interactive Mathematics Program, Ms. Gilliam continues to work with K-12 teachers in her state. She has authored two textbooks, *Investigating Mathematics: An Interactive Approach* (1994), and *Interactive Mathematics: Activities and Investigations* (1995). Ms. Gilliam chairs a committee for the California Mathematics Council and shares her work at mathematics conferences throughout the nation.

Kris Hall Neustadter is a resource specialist teacher at San Lorenzo Valley High School in Felton, California. She has 12 years of teaching experience and team-teaches with Sandie Gilliam. Ms. Neustadter received her bachelor's degree in American studies from the University of California, Santa Cruz, and completed graduate work in education at Chapman University, Orange County, California.

In the second segment, Ms. Gilliam introduces new concepts to her students by building on their prior knowledge of mathematics, history, and personal experience. She teaches abstract concepts of algebraic relationships in the concrete context of the journeys of early American pioneers. Through class activities and probing questions she surfaces her students' thinking in order to check for misconceptions. Ms. Gilliam asks her students to process and communicate their understandings in many ways—through oral, written, graphic, and symbolic representations. She actively engages them in making sense of new concepts by working through an authentic problem and sharing solutions with one another. Also featured in this video is Ms. Gilliam's team teacher, special education teacher, Kris Hall Neustadter.

Discussion of Session Video

To the Facilitator: You may want to pause the tape at the following points to discuss these questions. If you are watching a real-time broadcast on the Annenberg/CPB Channel, you may want to consider the questions as you watch and discuss some of them afterward.

1. Classifying Ideas (Fe MacLean)

Video Cue: *The Learning Classroom* icon fades out at approximately 5:45 into the program.

Audio Cue: Ms. MacLean says, "How do they move? The birds have wings, the fish have tail. Yes, Sarah? Which one of those has feet? Do they all have feet?" A student says, "Turtles and snakes." Ms. MacLean says, "Okay, some have feet."

- What do you think Ms. MacLean is trying to accomplish in this segment?
- When Ms. MacLean asks "Which ones have feet?" one student says turtles and snakes. What might you do to address this misconception if it arose in your classroom?
- What kind of schema is Ms. MacLean trying to help her students develop?

2. Creating a Performance Assessment (Fe MacLean)

Video Cue: *The Learning Classroom* icon fades out at approximately 7:00 into the program.

Audio Cue: Ms. MacLean says, "Each page represents—is a representative of—a particular group of animals and then the child makes a habitat or a setting for it. And so this is another one of the aids to help me assess whether or not they're understanding the concepts that we are learning."

- What specific things do you think the students might learn by creating this habitat book?
- What might Ms. MacLean learn when she uses the habitat book activity as an assessment?

IV. Session Activities, cont'd.

3. Using Journals and Free Writes (Fe MacLean)

Video Cue: *The Learning Classroom* icon fades out at approximately 8:45 into the program.

Audio Cue: Ms. MacLean says, "They read ... they write it down, they read it. If it doesn't make sense, they write it over. Or, they write, they think first and then clarify their thinking so that they can put it on paper. So, it is a tool in that sense."

- In your experience, does writing about something influence your thinking? If so, how?
- How might you use (or have you used) journals to assess your students' learning in your content area or grade level?

4. Creating Visualizations (Sandie Gilliam and Kris Hall Neustadter)

Video Cue: *The Learning Classroom* icon fades out at approximately 17:30 into the program.

Audio Cue: Ms. Hall Neustadter says, "Almost everything we do in mathematics here will start out with words and on the board in the big group, and then we bring it down to more individual ways of teaching everybody and with many visual aids."

- How do you think the use of visualization might enhance Ms. Hall Neustadter and Ms. Gilliam's students' understanding?
- How do the teachers move their students' understanding from these concrete visualizations to more abstract mathematics concepts?

5. Identifying Misconceptions (Sandie Gilliam)

Video Cue: *The Learning Classroom* icon fades out at approximately 20:00 into the program.

Audio Cue: Ms. Gilliam says, "Dots! Ok, and where would the dots be located, Jamie, the points?" Jamie says, "The corner of each of those boxes." Ms. Gilliam says, "The corner of each of those boxes. Thank you, Brett."

- How does Ms. Gilliam surface students' conceptions about graphing?
- In your own classroom, how do you (or might you) find out about and address a misconception that emerges from one or more students?

6. Probing for Students' Deeper Thinking (Sandie Gilliam)

Video Cue: *The Learning Classroom* icon fades out at approximately 22:15 into the program.

Audio Cue: Ms. Gilliam says, "The person at the board's gotta think, the students that are sitting back have to think, because they know those questions aren't going away and I'm not answering the questions."

- What do you notice about the kinds of questions Ms. Gilliam asks?
    - How can such questions provide information about how students are processing information?

V. Other Learning Activities and Assessments

To the Facilitator: These activities and assessments are for you to choose from according to your group's needs and interests. Many of the activities offered here would work equally well as assignments both inside and outside of class. You may want to use class time to prepare for and/or reflect on any activities assigned as homework.

Applications

1. Journal

a. Consider what you understand about how people process, organize, remember, and use information. What do you understand and what questions do you still have about these ideas? Reflect on how what you have learned about cognitive processing influences how you think about teaching.

b. In the session overview, three ways to enhance cognitive processing are described: 1) structuring the learning process, 2) organizing information and helping students to organize what they are learning, and 3) identifying students' strengths, preferences, prior knowledge and experiences. Referring back to this text (and the bulleted subcategories), choose one category and reflect on how you currently—or how you might in the future—use these ideas in your teaching. Give specific examples.

To the Facilitator: This would also be a good prompt for a free-write to share at the start of class.

2. Field Assignments

a. *Think aloud.* Much of what we know about cognitive processing comes from studies of novices and experts. Choose a specific problem in your own subject matter, and compare and contrast how you solve the problem with how one of your students solves the same problem. (Choose something well-defined like doing a specific long division problem or writing a five-paragraph essay on a particular topic.) First, take notes or speak into a tape recorder as you solve the problem on your own. Next, sit with a student and ask her to think aloud about her decisions and thought processes as she solves the problem. Here are some questions and prompts you might use with your student: Can you tell me in your own words what the problem is? Talk out loud as you begin to think about this problem. Talk about the approaches you are considering. What are you thinking now? What's difficult/easy about this problem? How do you know you're finished?

   Note: If a student finds this think-aloud process difficult, you can have students solve the problem on paper and then go back and tell you about his or her thinking process.

   Write a short paper comparing these two approaches to the same problem—yours and your student's. Discuss how your strategies compare with your student's. Consider the following: representing or conceptualizing the problem, planning, predicting, drawing on prior knowledge, recognizing patterns, drawing on core concepts, questioning, relying on resources (text, human, etc.), coping with difficulties, and monitoring yourself as you solve a problem.

V. Other Learning Activities and Assessments, cont'd.

b. *Observe a student.* Choose a student to observe and work with to better understand in terms of his cognitive processing. Consider the following questions:

   - What do you notice about your student's learning style or preferences?
     - How does he seem to process information most successfully—through visual, auditory, or kinesthetic modes, for example?
     - Do certain ways of learning or representing information seem more accessible or meaningful for him?
   - Ask your student to share a mental map of the subject or concept under study.
     - What kind of patterns and relationships does the student see?
     - What misconceptions are visible?
   - What aspects of his experience might help this student to make connections to the subject matter (e.g., look to family and home cultures, areas of interests, and areas of expertise)?
     - What examples or analogies might be drawn from his experiences?

3. Evaluate and Revise a Lesson

Redesign one of your lesson plans to take into account what you have learned about cognitive processing. Next, write a reflective piece to answer the following questions:

- What did you change?
- What else did you consider?
- How was your lesson transformed?

These more specific questions may help prompt your thinking:

- How did you change or adapt your lesson plan to accommodate different processing strengths or learning modalities (e.g., auditory, visual, kinesthetic)?
- How did you change or adapt your lesson plan to reveal students' relevant prior knowledge, skills, misconceptions?
- How did you change or adapt your lesson plan to focus on teaching for understanding and the application of knowledge and skills?
- How did you change or adapt your lesson plan to help students make connections between core concepts?
- How did you change or adapt your lesson plan to help your students develop their problem-solving skills?

V. Other Learning Activities and Assessments, cont'd.

4. Create an Action Plan

a. *Design an advance organizer for a particular lesson or unit you have planned.* An advance organizer can be as simple as the three main points you would like students to glean from a lecture or as complex as a tree diagram with multiple branches that illustrates how concepts are related. [See the text in the Session Overview for some examples of advance organizers.] First, describe the content you will be teaching. Next, reflect on the following questions:

   - What are the key concepts or principles you would like to communicate?
   - What relationships will be emphasized?
   - What will the advance organizer look like?
   - How will you present the advance organizer in class?
   - How do you anticipate the advance organizer will help students to understand and make connections?

b. *Develop a specific strategy for gaining further insight into your students' thinking and understanding.* In your plan, describe the following: 1) a key question about your students you would like answered (e.g., How do my students currently understand the concept of seasons? How do my students approach the task of note-taking? How do my students understand what algebraic variables are?); 2) a specific method for revealing their thinking processes (e.g., having them create an illustration, think aloud as they approach a task, answer specific questions you pose, explain in a one-on-one interview, write a reflective essay, etc.); and 3) how you might use the information you collect in teaching about this concept. Write a reflective piece that describes why you chose this particular question and strategy, and how the topic fits into the larger curriculum you are teaching. If time and context permit, implement this plan and reflect on what you have learned.

Checking for Understanding

1. Short-Answer Questions

a. How does experience affect the development of the brain?

b. Describe three strategies for enhancing the processing and retrieval of information.

c. Describe how experts and novices differ in their problem-solving strategies.

2. Essay Question

Cognitive science is based on a model of information processing. Construct a diagram or visual representation that illustrates what you have learned about how people process or manipulate information. Consider how people perceive, filter, remember, and sort information, as well as how they make associations and apply what they know to new problems. Write an explanation to accompany your visual representation.

V. Other Learning Activities and Assessments, cont'd.

3. Reflective Essay

Discuss how what you've learned about cognitive processing has helped you think about yourself as a learner and the way you teach your students.

- What have you learned about how people manipulate and store information?
- What ideas stand out for you as the most useful and helpful?
- How do you think these ideas might affect your own teaching?
- What questions remain for you about these issues?

Long-Term Assignments

Curriculum Case Study

Consider your case study learning problem from a cognitive processing perspective. (Note: If your curriculum case is on a unit you plan to teach in the future, answer in the form of what you project for that unit. You may have to anticipate some of your students' reactions.)

- How did you find out about your students' relevant prior knowledge and beliefs?
- What ideas and associations did you hope to build on and expand?
- What instructional activities did you plan to build on students' prior knowledge and skills?
- What did students need to remember and be able to apply or use?
- What core concepts did you intend students to understand?
- How did these concepts relate to one another and how did you help your students see these relationships?
- What misconceptions did you learn about that your students might hold?
- What kinds of expert strategies did you model or suggest for their inquiries or problem solving?

To the Facilitator: You will find other learning activities on the course Web site at www.learner.org/channel/courses/learning-classroom. You will want to look ahead to assign learners the reading and any homework for the next session.

VI. Web Sites and Organizations

Learning Sciences Institute: http://peabody.vanderbilt.edu/ctrs/lsi/

The Learning Sciences Institute, at Vanderbilt University, is a basic and applied research organization that focuses on how people learn, with special emphasis on how learning can be enhanced through technology and innovative teaching practices.

Learning, Research, and Development Center: http://www.lrdc.pitt.edu/default.htm

The Learning, Research, and Development Center, at the University of Pittsburgh, is a multidisciplinary research center whose mission is to understand and improve the learning of children and adults where they live and work—in schools, workplaces, museums, and other informal learning environments. This Web site includes research project descriptions and publications.

Project BETTER: Building Effective Teaching Through Educational Research: http://www.mdk12.org/practices/good_instruction/projectbetter/

The Project BETTER series, developed by the Maryland State Department of Education, summarizes current research on effective instruction to assist teachers in expanding and refining their repertoire of teaching strategies and to guide instructional planning and decision-making.

ALPS: The Thinking Classroom: http://learnweb.harvard.edu/alps/thinking/

Developed as part of the Active Learning Practice for School (ALPS) site and Harvard University's Project Zero, the Thinking Classroom Web site provides practical resources, including lesson plans and curriculum design tools, for teaching thinking in the classroom.

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Note that recommended readings are marked with an asterisk (*).

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