All processes of thought, conscious and unconscious, fall into the realm of cognition. These processes operate by manipulating information-laden mental representations, which are either retrieved from memory or constructed from sensory information. In this way, the mind can be understood as an information processor, continuously adding to its repertoire of mental representations as well as producing overt physical behaviors. The study of human cognition thus becomes the study of the information-processing characteristics of the mind: What is the nature of the representations? How are they manipulated? How much information can be active at once? Cognitive researchers are concerned with discovering such facts about cognition, with the overarching goal of explaining human behavior in its various forms.

The study of human cognition is relevant to many fields, and researchers from several disciplines have contributed to our understanding of the mind. These disciplines include psychology, philosophy, linguistics, artificial intelligence, anthropology, education, and neuroscience. In fact, many cognitive researchers are multidisciplinary, simultaneously working in a variety of fields, and interdisciplinary, integrating aspects of the different disciplines.

The growing field of cognitive science was born out of the perspective that cognitive research must span multiple disciplines. However, less than 50 years ago, the study of cognition was largely considered unscientific, at least among many psychologists in North America. To understand the current approach to the study of cognition, it is important to consider its origins, as well as its obstacles. It is not the goal of this article to provide a detailed historical review of inquiries into human cognition (for such a review, see Gardner, 1985). Rather, we focus on the relatively recent emergence of the information processing framework that permeates contemporary cognitive science, and consider various major areas of cognitive research.

The Cognitive Revolution

The modern approach to the study of human cognition was forged by a series of events in the mid-twentieth century, known as the cognitive revolution. While scholars continue to debate whether the cognitive revolution truly qualifies as a scientific revolution, the era certainly marks an important shift in psychological theory and methodology, especially for psychology in North America. In the first half of the twentieth century, experimental psychology in North America was dominated by behaviorism, which generally disavows the use of mentalistic explanations of behavior. Mentalistic terms, such as belief and desire, were branded as superfluous and unscientific, and removed from accepted terminology. Behaviorism came in a variety of forms, including theoretical behaviorism and methodological behaviorism. The methodological behaviorist did not necessarily dismiss the existence of mental constructs, but would argue that psychological science should not include such unobservable entities. Theoretical behaviorism went further, holding that mentalistic constructs could be reduced to overt behaviors. Under this view, remembering a certain stimulus, like a sugar cube or a foul-tasting liquid, amounts to producing a specific learned behavior in response to it. Rather than building explanatory theories, behaviorism had the goal of describing relationships between reinforcements and observable behavior. Such descriptions were, according to behaviorism’s founding father, Watson, as far as experimental psychology could and should progress.

The apparent scientific rigor of behaviorism played a large role in its rise to prominence in psychology. However, to many American psychologists of the mid-twentieth century, it became increasingly apparent that limiting psychology to a science of behavior would be inadequate for explaining learning and higher-order processes of problem solving, reasoning, and decision making. Evidence for this inadequacy came from various sources, including a central research area in behaviorism, animal learning. For example, studies finding that rats could quickly learn an association between ingesting salty water and illness or an association between a certain noise and a shock, but had difficulty learning other pairings of the same elements (salt with shock or noise with illness), seemed to defeat the notion that learning is purely a result of experiential factors. The behaviorist approach could also not explain instances of creative cognition where novel responses are generated.

It would be incorrect to assert that the decline of behaviorism in American psychology was immediate, or due to any single set of events (Miller, 2003). Indeed, behaviorism was widely debated and defended throughout the 1960s and into the 1970s in various areas of psychology. In addition, the shift from behaviorism to cognitivism that marks the cognitive revolution in American psychology was influenced by developments outside
of America. For example, the Swiss psychologist Jean Piaget argued that the organization of the human mind is shaped by biological factors, while Russian psychologist Lev Vygotsky stressed sociocultural influences. Besides advancing new theories of psychological development, these researchers provided examples that psychology could maintain its scientific rigor without the constraints of strict behaviorism.

The cognitive revolution was also fueled by developments outside of psychology, notably in the fields of linguistics and artificial intelligence (AI). The linguist Noam Chomsky’s famous critique of B. F. Skinner’s *Verbal Behavior* stands out as many to a critical event. Skinner, the leading behaviorist researcher of his era, attempted to provide an explanation of language strictly in terms of environmental input. Chomsky argued that behaviorist principles are inadequate to explain human verbal behavior, because language acquisition does not seem to develop as a function of the environmental conditions that are presented to the learner. Chomsky cited evidence of children’s rapid language learning, and of people's ability to create and comprehend entirely novel expressions. Chomsky argued that the external conditions are too impoverished to support such learning, and posited universal, innate language abilities. While Chomsky’s arguments did not settle the issue on language learning, they did, in the eyes of many, serve to defeat the purely behaviorist account.

Fueled by post-World War II interests in advancing science and technology, the field of AI flourished in the 1950s and 1960s, and played a crucial role in the rise of cognitivism. The birth of AI can be traced back to 1956, when an influential conference on AI was held at Dartmouth College (Miller, 2003). Attendees included John McCarthy, Marvin Minsky, Herbert Simon, and Allen Newell, each of whom became leading figures in AI and cognitive-science research for decades to come. AI labs around the United States began producing computer programs that were capable of carrying out tasks that were previously believed to require the highest human intellect, such as solving complex logic and math problems. The new synergy between computer science and psychology was apparent not only in the tasks that computers were programmed to perform, but also in how they carried these tasks out. For example, McCarthy’s List Processing (LISP) possessed a unique memory organization for its time, which stored not only the contents of independent entries, but also their connectedness. These memory trees allowed the computer to store complex relational structures, a powerful new tool.

With advancing computer technology bringing promise of creating AI, the abstract notion of the computer served as a powerful metaphor for the human mind. Broadbent is widely credited with developing this computer metaphor into the information-processing model of the mind, which has become the dominant model for cognitive science. The new idea was that the mind could be described in terms of input, internal representation, processing, and output. In this way, the mind was not only like a computer, it was a computer. Psychological theories could be legitimately instantiated in computer models, a view that more closely bound psychology to the field of AI.

**The Birth of Cognitive Psychology**

The emergence of new scientific fields outside psychology and the open consideration of alternative theoretical positions within psychology supported the birth of a new psychological field, one committed to the study of human cognition under the information-processing framework. The publication of Neisser’s *Cognitive Psychology* in 1967 marked the emergence of this new field. Neisser defined cognition as all of the processes that transform, reduce, elaborate, store, recover, and use sensory input. For Neisser, the realm of cognitive psychology included how actions and experiences are affected by perceptions, memories, and beliefs. Like behaviorists, cognitive psychologists apply a strict scientific method to study the mind, but unlike behaviorists, they accept the existence of internal mental states within their science.

Armed with the information-processing framework, cognitive psychologists set out to explore many new questions about the mind. A primary concern was the mind’s basic architecture: Is the mind comprised of distinct cognitive systems, and if so, how do these systems operate? Research on human memory was central in addressing these questions. Memory is not simply a storage system, but is thought to be actively engaged in all aspects of cognition. The memory system has three interrelated functions: encoding, storing, and retrieving information. Evidence from numerous studies suggested the existence of distinct, but interacting systems of memory, distinguished primarily by the duration that information is retained. First, there is sensory memory, which holds a large amount of incoming sensory information for only a few hundred milliseconds. There is thought to be a unique sensory store for each of the five senses, although visual sensory memory has received the most research attention. The next memory system is short-term memory, which receives input from sensory memory, and holds, by recent estimate (Cowan, 2001), about four chunks (i.e., meaningful units) of information for a few seconds. A more contemporary view, Baddeley’s model of working memory (e.g., Baddeley, 2007), emphasizes not only short-term storage, but also how information is manipulated in immediate memory. The most recent incarnation of the working-memory model consists of three distinct short-term memory subsystems, commanded by a central executive. One subsystem processes and stores visuospatial information, a second deals with phonological information.
(including speech), and a third integrates different modalities of information and integrates temporal information into an episodic representation. A final major memory system is long-term memory, characterized by its near-unlimited capacity and duration. Information working memory may be stored in long-term memory for later retrieval; however, the storage of information depends on many factors, including how it is processed during encoding. Long-term memory can also input information into working memory, affecting the interpretation and elaboration of its contents, and making information accessible for use in higher-order processes such as comprehension, problem solving, and reasoning.

The field of cognitive psychology, realizing the potential of information-processing theory and building on basic assumptions about the architecture of memory, flourished in the latter quarter of the twentieth century. New areas of research emerged, exploring a range of cognitive phenomena, from the most basic processes, such as perception and pattern recognition, to more complex, higher-order processes, like comprehension and problem solving. Traditionally, cognitive researchers aim to determine specific processes that underlie human performance using experiments that isolate the particular demands of any given task. Participants are usually presented with fine-grained variations of stimuli or tasks, and performance is typically measured in terms of response accuracy or reaction time. This approach is essentially reductionist in nature, but it allows for causal determinations to be made through adherence to the scientific principles of quantification and strict experimental control. Beyond the basic controlled experiment, cognitive scientists have a number of other approaches in their methodological arsenal. Cognitive modeling, the simulation of cognition through computer programs, is a popular tool for instantiating theories and pitting them against one another. Technology in neuroscience, particularly functional magnetic resonance imaging (fMRI), has made it possible to examine the online brain activity of normal adults. Similar recordings can be obtained in terms of event-related potentials (ERPs), eye movements, skin conductance, and pupil dilation. Verbal and video protocols also provide a rich source of data, including gestures and think-aloud reports, which may give insights into the behaviors that people engage in during cognitive tasks.

**Overview of Research in Cognition**

Given that one of the main goals of education is to train and inform students through instruction, research in cognition has direct application, especially with respect to issues of learning. There are several areas of cognitive research, including perception and attention, language acquisition and reading, memory, comprehension, problem solving and reasoning, and metacognition, which can all inform educational practice.

**Perception and Attention**

One of the most basic areas of research within cognitive science concerns perceptual and attentional processes, which serve as gatekeepers for stimuli and determine what is available for further cognitive processing. The extent to which information must be explicitly processed, how attention is drawn to or away from stimuli, and how often information needs to be attended to during learning, are important and well-studied topics (Pashler, 1998). Repeated exposure or practice is a central mechanism in skill and knowledge acquisition, and can result in automaticity and proceduralization of cognitive processes over time. These principles can inform our understanding of successful acquisition of spoken language, reading skills, and various problem-solving skills. A related literature explores individual differences in the ability to control one's attention, or the ability to focus on a goal in the face of interference. Research has found that these abilities affect the amount of information that people can consider in immediate memory, which in turn impacts their performance on many cognitive tasks. As such, the ability to control one's attention has also been referred to as working-memory capacity (Conway et al., 2005).

**Language Acquisition and Reading**

First-language acquisition is perhaps the most impressive of all cognitive skills. Language develops universally in some form in all humans, and development typically proceeds in a remarkably rapid fashion. Present approaches emphasize both the biological predisposition to acquire language as well as the role of exposure to patterns in the environment (Gleitman and Newport, 1995). The differences between first-language acquisition occurring in infancy, and second-language acquisition that occurs afterward, are important issues, as are the questions of how bilinguals represent and process information in their second language (Kroll and Tokowicz, 2005). Additionally, recent research has highlighted several cognitive advantages among young bilingual students and aging bilingual adults, including superior executive functioning and facilitated acquisition of reading skills (Stock, 2001). A great deal of cognitive research has also explored reading behavior more generally. This research supports two important conclusions: that mastering the alphabetic principle (that written symbols correspond to sounds, or phonics) is essential to becoming proficient, and that methods that teach the alphabetic–decoding principles that underlie our written language are more effective than methods that do not, especially for children who are having difficulty learning to read (Rayner et al., 2001).
Memory

The relevance of cognitive research on memory is perhaps obvious if a main goal of education is the acquisition of knowledge. Memory research concerns the mechanisms that enable the encoding, storage, and retrieval of new information. A long tradition of research has demonstrated more durable learning and memory result from spaced practice (Cepeda et al., 2006), and when information is presented in a context that allows for imagery, elaboration, or integration with prior knowledge (Baddeley, 2007). Other highly relevant lines of investigation examine how memory tests affect subsequent memory for information, in some cases by introducing false memory traces through distractors in multiple-choice tests (Roediger and Karpicke, 2006). Testing may also cause patterns of facilitation for the tested information, and interference for nonretrieved information.

Comprehension and Conceptual Understanding

Perhaps the most common medium for subject-matter transmission is through expository text, with lectures and discussion also being common forms of instruction. In these cases, learning depends on text and discourse processing which is another major area of cognitive research. As information is processed, multiple levels of representation are constructed, and as Kintsch (1998) has suggested, it is especially the deepest level of representation, called the situation model, that represents understanding or comprehension of phenomena. This area of research has explored the contexts and individual differences that support construction of better-situation models during learning, including encouraging the activation or use of prior knowledge and encouraging active processing through tasks such as question-asking or self-explanation (Graesser et al., 1997; McNamara, 2007). A special case of learning occurs when new information or evidence in some way conflicts with prior understandings. In these cases, conceptual change or belief change may be required, especially for learning in science (Chi, 2000; Chinn and Malhotra, 2002).

Problem Solving and Reasoning

A great deal of research on problem solving has been informed by using a contrastive approach — comparing better or more expert problem solvers to less-effective, or less-expert, problem solvers. This work has shown that experts use their experience to see the deep (more explanatory) structure of a problem, while novices often process problems at a superficial level. This line of research has in fact spurred the research on self-explanation cited above (Chi, 2000). In a similar vein, instruction that emphasizes procedural elements of math problem solving can promote shallow understanding, while conceptual or mixed approaches can lead to better understanding as well as improvement in procedural skill (Siegler, 2003). A third important area of problem-solving research has explored the effectiveness of scaffolded practice, worked examples, and feedback (Atkinson et al., 2000).

Ill-structured problems represent a special class, where solutions, goals, and assumptions are less constrained. But even here, expertise in a domain gives the solver ways to constrain the problem space (Voss et al., 1983) and turn the problem into a well-structured one. Solving this type of problem, where no single agreed-upon answer exists, requires argumentation or informal reasoning skills. In such cases, the reasoner must consider the evidence and arguments and whether they provide support for conclusions. Such skills underlie disciplinary thinking in both the humanities and the sciences, as well as reasoning in most everyday contexts. Thus, the development of scientific reasoning and argumentation skills in students has been an area of much recent interest.

As opposed to these skills of informal reasoning, formal reasoning relies on the application of the rules of logic or mathematics, with the goal of determining the validity of syllogistic or propositional arguments. Formal-reasoning performance often improves with more familiar or meaningful contexts, as well as when arguments are phrased in more intuitive language. Several forms of reasoning have been found to improve with training in statistics, but generally, people tend to be poor at all types of reasoning without training. Substantial individual differences in reasoning abilities have been attributed to thinking dispositions (Stanovich et al., 2003) which have been found to correlate with the ability to learn and engage in many higher-order cognitive tasks. This in turn suggests a critical role for instruction in reasoning that is largely absent from our current curricula.

Metacognition

Metacognition is the act of monitoring cognitive performance, which serves as input to self-regulation of cognitive behaviors such as studying. Much research on this topic has used prediction paradigms for memory and comprehension tasks. Metamemory paradigms typically consist of the task of learning word pairs, such as a word in a foreign language and its English translation. When students are asked to predict their ability to recall a translation, metamemory accuracy has been found to be quite good, especially when judgments are made at a delay (Dunlosky et al., 2007). Predictive accuracy for comprehension tests following the reading of expository texts is typically much lower, although recently some contexts that promote accurate metacomprehension have been found. When readers are asked to self-explain while reading, or to generate summaries or keywords at a delay before making their judgments, metacomprehension accuracy can be substantially improved (Thiede et al., 2009). The
ultimate value of supporting better predictive accuracy among students is that it then can help them to make effective decisions of what material to re-study as they attempt to learn material on their own.

Recent Trends

Transfer

The goal of instruction is ultimately to promote learning that transfers to new problems and situations, especially ones that are quite dissimilar from the initial learning context. When students are able to activate prior knowledge or learned-solution strategies and apply them by analogy in novel contexts, it is referred to as far transfer. However, a recurring theme in the cognitive literature is that students often fail to activate relevant prior knowledge as they process new information. Thus, little experimental evidence has supported the existence of far transfer (Barnett and Ceci, 2002). More often than not, people are unlikely to recall critical information in situations that are superficially dissimilar to the context of acquisition. Despite the elusiveness of findings of far transfer in cognitive laboratories, there is evidence from observational studies that people can and do apply analogies to solve novel problems in the real world. Scientists, for example, spontaneously construct analogies to help solve problems that they encounter in their research. One reason for the apparent void between laboratory and observational findings could be that experimental participants are not able to represent the analog at a level of abstraction that is sufficient to support transfer. The issue of whether initial instruction should be concrete and contextualized, versus abstract and symbolic, is currently receiving a great deal of attention, with some advantages being found for each mode of acquisition. When students are taught a principle through concrete examples that gradually become more abstract, they are better able to transfer the principle in some contexts (Goldstone et al., 2008). However, in other contexts, starting with abstract or symbolic representations leads to better learning and transfer, as concrete representations may distract learners from recognizing the basic principles.

Spatial Thinking and Gesture

Spatial skills are thought to be important to many aspects of cognition, including thinking and problem solving in math and science domains. Individual differences in spatial ability have been well documented, and recent work is attempting to differentiate among distinct subtypes of spatial abilities (Hegarty and Waller, 2005). One important aspect of spatial thought is the ability to parse, mentally manipulate, and use symbolic representations, such as maps and diagrams. To the extent that spatial skills affect learning and understanding, it is particularly encouraging that such skills do seem to improve with practice or input from the environment (Newcombe and Huttenlocher, 2000). Another important aspect of spatial cognition is the bodily gestures that people produce (Alibali, 2005). Gestures can be used to support spatial thinking and communication, but also may be used to express knowledge that is difficult to verbalize. Gestures may reveal a student's preparedness for learning a concept even when their verbal expressions suggest poor understanding. Interestingly, gestures seem to be used much for the self as for others. Such findings suggest that cognitive processes may be tied to the body's interactions with the world, and an extreme version of this perspective, referred to as embodied cognition, is receiving a great deal of attention in the recent literature.

Culture and Cognition

Research in early science education and developmental psychology has demonstrated that most children need to overcome some of their intuitive ideas of the world around them in order to comprehend scientifically accurate explanation of phenomena. However, the vast majority of this work has involved children in mainstream, North American, urban, technologically dependent populations. Recent work by Medin and his colleagues has shown how intuitive concepts are shaped by society, and how children in specific cultures (such as Native American communities) differ in their understandings of biological concepts (Bang et al., 2007). These differences are attributed to exposure to cultural values and beliefs transmitted through the discourse within the community. Interestingly, children in Native American communities were found to have more advanced understandings of living things and ecologies. Yet, disturbingly, they did less well than mainstream students in academic classroom performance. These results suggest conflicts between traditional science instruction and the ways of thinking instilled by different communities. Such findings highlight the need to recognize the differences in intuitive understandings that children from many different kinds of communities bring to the classroom, and represent one example of the recent research trend to better understand the interaction of culture and cognition.

Collaboration

A final trend in recent research explores the impact of social interaction on learning. The communication between the teacher and a class is essentially a social interaction, but because of the number of students, it is essentially one-sided. The teacher necessarily becomes the transmitter of information, and there is little role for either individualized discourse or interactive activity on the part of most students. Thus, it is not surprising that researchers have attempted to
increase interactive communication for all students through the creation of small group exercises, peer-collaboration activities, or intelligent tutoring environments. Interacting with others can be particularly motivating, but there are also a number of pitfalls that can make collaborative learning less successful than individual work. Intelligent tutors can provide students with timely feedback and expert knowledge, but if systems provide too much scaffolding or help, then the students may never actually engage with the content (Anderson et al., 1995). Alternatively, working with peers can be quite motivating and effective as a supplement to classroom instruction, but guidance for students on how to collaborate is critical, otherwise they may engage in superficial discussions that do not reach a high level of discourse (O’Donnell and King, 1999). The goal of current investigations is determining which contexts are most effective and in what ways, for different subject matters, and different kinds of students (VanLehn et al., 2007), as well as the discovery of the mechanisms that are responsible for successful collaborative learning and transfer.

See also: Cognition and Emotion; Concept Learning; Memory; Metacognition; Neuroscience Bases of Learning; Problem Solving and Human Expertise; Problem Solving and Reasoning; The Adult Development of Cognition and Learning.

Bibliography


