OBSERVER

Published by the American Psychological Society

SPECIAL ISSUE FEBRUARY 1998

REPORT 6

Basic Research in Psychological Science

A HUMAN CAPITAL INITIATIVE REPORT

Basic Research in Psychological Science
A Human Capital Initiative Report

Sponsoring Organizations

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American Psychological Society

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Thanks also to
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United Kingdom
for contributing to this report.

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APS OBSERVER Special Issue

BASIC RESEARCH IN PSYCHOLOGICAL SCIENCE

A HUMAN CAPITAL INITIATIVE REPORT

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Preface

THE HUMAN CAPITAL INITIATIVE

Since 1990, the psychological science community has been developing a national behavioral science research agenda that illustrates the potential of behavioral science research in addressing critical areas of concern to this country. The first stage of the process began in January 1990, when more than 100 researchers representing 65 psychological science organizations and half a dozen federal agencies gathered in Tucson, Arizona, for what was to be the first of several Behavioral Science Summit meetings. The number of organizations represented in later meetings grew to near 80. (The next Summit, "Advancing the Scientific Base of Psychological Science: Achievements, Obstacles, and Opportunities," will be in May 1998.)

Convened under the sponsorship of the American Psychological Society (APS), the Summit participants began by addressing this basic question: Given the array of different scientific perspectives within behavioral science, from brain research to the study of the whole person, to social and organizational research, was there enough of a common bond to warrant a joint, large-scale research effort? Finding substantial agreement that in fact there are a number of common bonds across this diverse field, the Summit participants endorsed the development of a research agenda that would help policymakers in federal agencies set funding priorities for psychological and related sciences.

The result was the Human Capital Initiative (HCI), a framework for a sustained research effort published in 1992. It targeted six problems facing the nation, communities, and families — Aging, Literacy, Productivity, Substance Abuse, Health, and Violence — and described these issues in terms of psychological research. The six broad areas of national concern in the original HCI were not meant to limit the specific research initiatives that might come forward. Rather, they were intended to serve as starting points to stimulate research that adds to both theoretical and practical knowledge of these and other crucial issues.

Using the 1992 HCI document as an umbrella structure, groups of individual investigators representing their scientific disciplines have developed a number of specific research initiatives. This report is part of that series. Other specific HCI reports have focused on areas such as productivity in the changing workplace, productive aging, violence, health and behavior, and psychopathology. (Copies of the HCI reports are available from APS.) Development of these specific initiatives is overseen by the Human Capital Initiative Coordinating Committee (see page 2).

The HCI and the National Science Foundation — Soon after the 1990 Summit, the U.S. Senate Appropriations Committee took note of "a summit meeting of over 65 behavioral and psychological scientific organizations" whose "participants developed a human capital initiative...outlining general psychology research themes." In the same report, the Committee urged the National Science Foundation (NSF) and other research funding agencies "to examine the summit meeting documents with an eye toward behavioral science funding initiatives in 1991." Since then, both the Senate and the House have continuously urged NSF to use the HCI in determining its behavioral science research priorities.

In adopting the HCI as an NSF initiative, the content was expanded to encompass all of the social sciences as well as psychology, taking on new, more applied directions than the original behavioral science document. As a consequence, basic research in the psychological sciences became relatively underrepresented in NSF's HCI program.

Although the structure and substance of the 1992 HCI was broad and forward-looking at the time, the pace of progress in psychological research requires updates to the illustrations of advances in basic knowledge in the field—"what we know"—and the research questions to be addressed—"what we need to know." Equally important, there is a need to coordinate the scientific agenda in psychology's HCI with the research priorities in NSF's HCI, particularly to clarify where basic research in the psychological sciences fits in the NSF HCI. One goal of this report is to provide examples of current areas of psychological science where further development is most likely to enhance understanding of the issues identified in the HCI developed by NSF, and to increase the fit between that initiative and basic research questions in psychology.

ACKNOWLEDGMENTS

This report was developed under the auspices of the American Psychological Society with support from the National Science Foundation. We wish to thank the National Science Foundation for its dedication to basic research in psychological science and for its continuing commitment to the Human Capital Initiative.

We are grateful for the efforts of the people who participated in the workshop on which this report is based. Their names appear on page 2 of this report. Each one is a national leader in his or her field, and each contributed enormously. Project Director Alan G. Kraut and Editor Sarah Brookhart are given special thanks and recognition for their efforts in putting this report together.

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BASIC RESEARCH IN PSYCHOLOGICAL SCIENCE

A HUMAN CAPITAL INITIATIVE REPORT

Introduction

The term "human capital" is familiar to many as a term that originated in economics. In the Human Capital Initiative (HCI), this term has been borrowed and broadened to reflect the view that human potential is a basic resource and that understanding the human mind and behavior is crucial to maximizing human potential. To achieve the goal of maximizing human potential, we need to know in scientific terms how people interact with their environment and each other — how we learn, remember, and express ourselves as individuals and in groups — and we need to know the factors that influence and modify these behaviors.

This report, *Basic Research in Psychological Science*, describes theoretical advances that have been achieved in studying and understanding various psychological and behavioral phenomena. The topics discussed here—the auditory system, visual attention, memory, social cognition and stereotyping, culture and cognition, emotions, decision making, development, expertise, and social coordination—represent just a few of the areas of study that constitute basic psychological science. These topics are presented not as a comprehensive record of all that is taking place in the field, but as a sampler from which it is hoped the reader will gain a sense not just of the progress in these individual areas, but of the breadth and depth of the theoretical work going on in the field as a whole.

In describing the various areas of research, the emphasis is on identifying within each field: (1) areas where sufficient recent advances have been made at the level of basic research and are now ready to be put into use; (2) classic basic research questions that are still underdeveloped but have considerable potential for spinoff implications and for solving problems of human potential if given sufficient investment; and (3) areas of interdisciplinary research that are driven by fundamental psychological research questions.

In addition to describing theoretical advances in psychological science, this report addresses future directions of research in the field, pointing to new areas of research that build on the understanding and knowledge produced through previous basic research. Cross-cutting methodological issues and technological innovations also are discussed, illustrating how experimental tools such as computer modeling and neuroimaging have enabled psychological scientists to test their theoretical ideas at a level of complexity that matches the phenomena being studied. Many of the new directions and methodologies discussed in this report involve interdisciplinary research; the most complete understanding and knowledge of complex psychological processes comes from research that draws on the theories and methods spanning psychological, social, cultural, and biological perspectives. As our understanding of the interplay among these areas grows, there is increased momentum for collaborative research that draws on theories and methodologies from a wide range of disciplines.

These topics are presented not as a comprehensive record of all that is taking place in the field, but as a sampler from which it is hoped the reader will gain a sense not just of the progress in these individual areas, but of the breadth and depth of the theoretical work going on in the field as a whole.

Finally, it should be noted that this report is intended to portray basic research in psychology for a wide variety of audiences: to inform those within the behavioral and social sciences about developments in areas related to their own research; to educate researchers and others outside of psychology about new scientific perspectives on issues of common concern; to provide guidance to policymakers who are planning and funding research programs; and to enhance the scientific literacy of the general public.

The development of effective hearing aids is a subject of national concern, particularly as a larger percentage of the population grows into presbycusis (age-related hearing loss).... In recent years, collaborative efforts by psychologists and other investigators in basic auditory research, speech scientists, computer scientists and engineers have led to a variety of new ideas and solutions that are finding their way into a new class of miniaturized digital hearing aids.

The Auditory System: Making Sense of Hearing

We can literally hear the progress of research on the auditory system, which has led to improvements in prosthesis design and communication technology.

In the past 20 years, we have witnessed extraordinary advances in our knowledge of sensory systems. Below are examples of the achievements that have occurred in just one area, the auditory system. But these advances exemplify a similar progress occurring in our understanding of the processes involved in the visual system and the systems of taste, touch, and smell. Among other things, this progress is resulting in improved health care, communications, and technology.

Achievements in Auditory Research

The auditory system has many components and is studied from a variety of perspectives. Research on hearing has identified the perceptual and physiological responses to basic features of sound, such as frequency, temporal configuration, and intensity. This work has led to sophisticated models of the fundamentals of hearing, ranging from cochlear mechanics and the activities of neurons in the auditory system to basic auditory perception. Well-supported theories of higher level processes—complex pitch and loudness perception, component interactions, and sound localization—have provided the foundation for a burgeoning effort to understand cognitive aspects of hearing, such as speech, signal processing in complex acoustic environments, music, and auditory attention. In turn, this research has found important applications in prosthesis design and communication. It should be noted that in addition to the substantial contributions of basic psychological science, many of the advances in our knowledge of the auditory system have been achieved through interdisciplinary efforts involving psycho-acousticians, auditory physiologists and biophysicists.

Auditory Prostheses — The development of effective hearing aids is a subject of national concern, particularly as a larger percentage of the population grows into presbycusis (age-related hearing loss). The most common complaints about hearing aids are that they are loud and painful, and that they do not add to the comprehension of speech in noisy situations. In recent years, collaborative efforts by psychologists and other investigators in basic auditory research, speech scientists, computer scientists, and engineers have led to a variety of new ideas and solutions that are finding their way into a new class of miniaturized digital hearing aids. For example, through basic research, it has been discovered that individuals with some types of hearing loss experience an escalation of loudness. This is now being addressed in hearing aids by the inclusion of band-limited automatic gain control (AGC) circuits that compress the signal in a way that is similar to the functioning of the normal ear. Not only is intelligibility improved by allowing soft consonants to be heard, but the input-output characteristics of AGC can be individually tailored in order to allow more normal perception of loudness.

Similar use of basic research is found in prostheses that are designed to offset the loss of normal outer hair cells, by identifying significant peaks in the speech spectrum and reducing energy in frequency regions around them, and through attempts to mimic the functioning of the normal cochlea through algorithms that suppress frequencies below spectral peaks. (Basic research has also discounted the long-held assumption that speech intelligibility can be improved by amplification of spectral peaks.) The results of multidisciplinary collaboration in the development of hearing aids have been spectacular, greatly improving the quality of life for hearing-impaired listeners by allowing them to process speech and music in a variety of acoustic environments.

A similar approach is seen in work with cochlear implants, which are electrical devices designed to bypass a nonfunctioning ear. As is the case with hearing aids, major contributions to this effort have come from basic science in speech and in developmental psycholinguistics, where investigators are studying the potential impact on young children who must learn spoken language through implants.

Information Compression — Aside from leading to a fuller understanding of brain function, knowledge of the properties of the auditory system and other sensory systems allows communication devices to be tailored to human needs in many ways. One such advance is the development of information compression, in which "perceptual coding," described below, is used to reduce the information bandwidth required to transmit a message or picture with no apparent loss in quality for the human observer.

The fidelity of a communication channel depends both on the accuracy of resolution in the message and on the resolving power of the receiver. Improvements in channel capacity are sometimes treated simply as a matter of increasing physical resources devoted to the communication. This improvement of channel capacity by "brute force" — that is, adding more bits — can be expensive to the point of being prohibitive. For example, we still do not have visual telephones although we have the technology to broadcast pictures and sound. The problem is that there is simply not enough capacity in the transmission lines (wires, microwaves, satellites, etc.) to support the infrastructure of a full-fledged visual telephone system.

A promising alternative to adding more bits lies in redistributing the bits in ways that essentially reduce the accuracy of some parts of the message to increase accuracy in others. The information algorithms to do so are appearing in such devices as miniature compact disks and high-definition TV. In this solution, the algorithm takes information (bits) away from one part of the message where it is not needed and assigns that information to another part of the message where it improves perceptual precision.

To do this with minimal perceptual loss requires a thorough understanding of the details of the perceptual resolving power of the receiver. For example, psychophysically based knowledge about such auditory factors as critical band filtering (a frequency band outside of which signals do not interact directly with those within the band) and the upward spread of masking (a lower frequency tone masks a higher frequency far more than the other way around) allows us to predict which aspects of the sound wave do not need to be sent with great precision and which aspects do. This is accomplished by removing bits from the part of the message that the listener already processes poorly and devoting those bits to the part of the message where accuracy is important. Similar processes remove bits from a point in the television picture where people will not notice their absence, such as next to a bright white spot, and use them to enhance contrast elsewhere. The general name given to this kind of engineering is perceptual coding.

Information compression relating to the different sensory modalities has been used in other ways. For example, data compression techniques have been combined across sensory systems to produce multimodal displays with sufficiently low bandwidth that real-time delivery is minimally compromised. Multimodal displays are useful not only to transmit information about ongoing events, as in telesurgery, but also in simulations and virtual environments. The uses of these displays go beyond communication and entertainment, to such applications as training technologies and multimodal computer-assisted design (CAD) systems.

Future Directions in Auditory Research

Interdisciplinary Model of Hearing — Among the most important projects now under way in auditory science is the interdisciplinary search for a complete model of hearing that includes all known features of the auditory system, from the cochlea through the auditory cortex, in the context of all known features of auditory behavior, including pitch, loudness and spatial hearing. A leading example of this effort is the Auditory Image Model, which currently includes the acoustic properties of outer and middle ear mechanisms, and is drawing from current thinking about non-linear processes in cochlear mechanics, molecular studies of corti and otoacoustic emissions, as well as intracellular recordings from auditory hair cells, plus a model of the auditory nerve based on recordings from single neural units as well as observations of the effects of stimulating the cochlear nerves. Soon to be added is a burgeoning physiological database collected from work involving various nuclei in the brain stem and work on cells responsible for binaural interaction, with many of the higher order auditory interactions modeled through the use of various techniques such as recordings from in vitro samples.

> ***As is the case with hearing aids, major contributions to [work in cochlear implants] have come from basic science in speech and in developmental psycholinguistics, where investigators are studying the potential impact on young children who must learn spoken language through implants.***

Knowledge of the features of speech is guiding the research questions being asked about individual neurons as well as shaping the kinds of multifrequency interactions that are included in the grand model. In addition, there is a great deal of interest in the auditory cortex, as research in this area moves beyond single-unit studies to work with human listeners and neural imaging. The next five to ten years should produce a powerful physiological model of the entire system that will be of enormous value for testing theories relating to behavioral functions.[1]

Higher Order Hearing — Within auditory psychophysics, we are seeing a steady movement toward the higher order features of hearing. Examples include investigations at the intersection between basic psychoacoustics and speech, examinations of combined factors such as the precedence effect in spatial hearing (as in a movie theater where the sound from some speakers is delayed to produce a relatively uniform sound level that seems to have the screen as its source), work in the basic features of music perception, and a growing interest in auditory attention and its relation to non-modal-specific views of attention. These factors are central for the design of improved hearing aids, a goal that requires research from a broad spectrum of disciplines.

[1] See "Cross-Cutting Issues" for additional discussion of modeling in basic research in psychology.

Visual Attention: Understanding the Mind's Eye

The brain can take in only so much information at one time. Here is a scientific look at the perceptual processes involved in what we see and sometimes don't se

Air traffic controllers, assembly line inspectors, and professional athletes all have at least one thing in common: Visual attention is a critical component in their jobs. In fact, attention is central to everyone's mental life. Our perceptions, our thoughts, our decisions, all involve underlying mechanisms of attention that govern what we see and hear, what we learn and remember, and what actions we take. Through these mechanisms, we manage — and avoid being overwhelmed by — the enormous amount of sensory input from our natural and social environments.

In the past 40 years, basic psychological research has greatly increased our understanding of the underlying processes of attention. Theoretical approaches to attention from a variety of perspectives, including cognition, vision, memory, animal behavior, and development, are yielding a wealth of scientific knowledge that can be used to enhance such diverse activities as the screening of applicants for hazardous jobs; the design of monitoring devices such as computer displays, airplane cockpits, or radar screens; and the design of classroom environments.

Some examples of central findings from this research are presented below, with particular emphasis on how the processes involved in attention may contribute to or impede the optimal use of our human potential. Much of the focus here is on aspects of visual attention, but it should be noted that attention is equally important in hearing and in the other senses.

In the past 40 years, basic psychological research has greatly increased our understanding of the underlying processes of attention. Theoretical approaches to attention ... are yielding a wealth of scientific knowledge that can be used to enhance such diverse activities as the screening of applicants for hazardous jobs; the design of monitoring devices such as computer displays, airplane cockpits, or radar screens; and the design of classroom environments.

Findings and Opportunities in Basic Research in Visual Attention

Attention in Learning, Skill Acquisition, and Memory — The roles of attention in memory and in the acquisition of mental and motor skills are crucial issues in attention theory and in practical life. Because our attentional capacity is finite, we need the ability to delegate control of well-learned operations to unconscious routines, leaving us able to focus on new information and unpredictable decisions. The ability to do this — to make performance automatic—is vital to efficient thinking and action. For example, the fact that we have some guarantee that we will automatically stop at a red light (that is, we don't have to abandon all other thoughts to focus on the process of applying the brake) or follow our usual route on the highway without having to focus solely on navigating allows us to daydream or to focus on an intellectual problem while driving home. Similarly, in solving a complicated mathematical problem, we are helped by having the answers to simple computations automatically pop into our minds when needed without our having to search for the answers.

For researchers, a central question is: What changes occur when an attention-demanding task becomes automatic? We know that many tasks which initially require attention become routine and virtually unconscious with repetition. Recent research on extended practice has shown that there is surprising plasticity in the learning mechanisms, but also considerable specificity in what is learned. We often acquire skills that closely match the particular context of learning and must relearn them when something is changed.

Some forms of learning require conscious attention, but others appear not to. When learning occurs independently of attention, we may have no awareness of what we have learned. This learning appears to depend on memory systems separate from those that underlie voluntary recall. Deliberate conscious retrieval of memories depends on attention at the time of acquisition. Skills or information learned without awareness cannot be explicitly recalled, but may be revealed through increased fluency in performance, or by primed responses to the learned stimuli.[1] Divided attention, doing two tasks at once, reduces conscious memory but seems to leave unconscious influences from either task as strong as they would be with focused attention to that task alone. As a result, we may have little control over memories that are acquired in conditions where attention was divided and conscious monitoring reduced.

One of the most important effects of attention on memory seems to be to make the memory available later for conscious voluntary recall. Research has shown that this probably depends on establishing links to the context of the memory. Attention seems to be needed to form the complex links and hierarchical structures through which items or events are mentally related to their contexts. Thus, if subjects hear a list of word pairs while their attention is focused on some other task, they are more likely subsequently to show priming for the individual words than for the associations between them.

Inattentional Blindness — Attention is the gateway to awareness. Events that are not selected by attention go unregistered in the conscious mind. Consequently, people's experience of the world is limited, not by sensory factors such as bad eyesight, which can most often be corrected, but by attentional factors. The limits imposed by attention are so dramatic and so commonplace that they have been labeled "inattentional blindness."

A number of studies have shown that people are unaware of major changes in a scene if the changes occur during a blink, an eye movement, or even some other larger distracting event. Here is an example of the latter: A researcher pretends to be lost in a town and begins to get help from a passer-by when some construction workers walk between them, carrying a door. As the door moves through, the first researcher changes places with the trailing door holder (who is on the other side of the door from the passer-by/subject). The passer-by is now talking to a different person who has different clothes and a different voice, but is still holding a map and still talking about how to get somewhere in town. Fifty percent of those providing directions do not notice the substitution, even when explicitly asked later. Despite the fact that major changes happen right in front of one's eyes, they go unnoticed if attention is not focused on the event as it happens.

This inattentional blindness may be greatest at the center of the gaze, where vision is normally most accurate, so that we can easily miss events occurring right where we are looking and where we might feel most confident that we are paying attention. This misplaced confidence can lead to serious errors in hazardous tasks monitored by human operators.

A related phenomenon in which important signals may be completely missed has been labeled the "attentional blink." When two targets are presented in a rapid sequence of irrelevant items, the second is often missed, even when the two are separated by an interval of up to seven-tenths of a second. Asking a subject to detect or name even a simple shape or color flashed on a screen causes him or her to miss whatever might be flashed next. Detecting and noting the occurrence of the first target appears to preempt awareness for a short period, making us blind to the second. This effect depends on the first target being relevant; if the first can safely be ignored (e.g., because the instructions say to pay no attention), detection of the second is unimpaired, so the difficulty is clearly attentional, not sensory. That is, depending on the circumstances, either the first or the second target can be seen. Because of this phenomenon, accidents may occur in tasks involving rapid sequential monitoring, such as in driving a car or handling an airplane, and faults may be missed in assembly lines when two relevant signals are presented in rapid succession.

Attention to internal ideas can produce a similar blindness to external events. In the laboratory, this has been demonstrated in an experiment in which participants were asked to do mental arithmetic while also watching for a particular letter in a rapid sequence of other letters. The more effort that was needed at any moment for the arithmetic task, the more likely a subject was to miss the target letter, even though that is what the subjects were asked and expecting to do. One interesting note on the measurement of attention: The subject's amount of internal effort needed at each moment for tasks such as mental arithmetic can be indexed by the size of the eye's pupil, which has been shown to correlate with task difficulty. The main point, however, is that when attention "goes internal," we may stop perceiving the external world.

As these examples show, we cannot be completely confident that we are aware of — and have accurately taken stock of — the scene around us. The problem is twofold: First, the limits of attention restrict our awareness of events around us; and second, we are not aware that we have such limitations. The implications of inattentional blindness are clear, especially in potentially hazardous situations. It poses a significant danger in attentionally demanding tasks such as driving, or in professions like air traffic control, in which a number of events must be monitored simultaneously. Individuals in such circumstances may find themselves unable to register critical events that if undetected may lead to accidents.

Perceptual Limits in Attention — Attention is essential in certain visual search tasks but not in others. When the target we are seeking is defined by a simple feature, like a unique color, size, or orientation, it typically "pops out" of its surroundings without the need for focused attention. However, when it is distinguished only by a combination of features, like a green *H* among green *X*s and blue *H*s, or by the absence of a feature, like an *O* among *Q*s, we often have to focus attention on each item in turn to find the target. Thus, when attention is global—that is, spread over the whole visual field—the information we perceive is apparently limited to simple feature differences. Using global attention, we segregate the scene into discrete areas, select candidate objects for later identification, and monitor for salient stimuli and unexpected events.

There is growing evidence that the brain is organized in a partly modular fashion, with specialized subsystems dedicated to

[1]See "The Nature (and Fallibility) of Memory" for additional discussion.

particular forms of processing. For example, particular brain areas have been shown to be active when a subject is attending to motion, and other areas are active when a subject is attending to color or shape. (Damage to the areas may result in the selective loss of the ability to see motion, or color, or shape.) There are clear advantages to such specialization. However, the cost is that information from a shared source is distributed across different subsystems and must be related back to the correct original source. This poses what has become known as the "binding problem." Some striking illusions illustrate failures of binding when too many objects are presented at once. For example, when a green *X*, a red *O*, and a blue *T* are briefly flashed, participants will often report illusory conjunctions like a red *X* or a green *T*. An attentional cue to the spatial location of a target—for example, a pointer indicating the location of the relevant item—flashed just before the display, eliminates these binding errors and suggests a central role for spatial attention in solving the binding problem.

This hypothesis recently gained support from findings in neuroscience, both from brain imaging and from studies of brain-damaged patients. Positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have shown that parietal areas of the brain are activated both in a task that requires spatial shifts of attention and in a search task for conjunction targets, thus linking spatial attention to binding. Patients with bilateral damage to the parietal lobes are typically unable to localize objects in space. A recent case study showed that they may also have a major deficit in binding features. This research on attention and binding illustrates the increasing benefits of the interdisciplinary approach known as cognitive neuroscience.[1]

Attention in Dynamic Displays — Attention is also needed when we keep track of objects as they move or change in dynamic displays. Consider a basketball player keeping track of teammates and opponents, an air traffic controller monitoring several aircraft on approach, an airline pilot checking on warning lights, pitch and yaw displays, radio-guided approach information and the runway in front of the plane, or even a pedestrian negotiating a busy intersection filled with cars, bicycles, and other pedestrians. Research has indicated that no more than four or five independent elements can be tracked accurately at the same time, even when these are simple identical moving dots. Recent work on attentive pursuit shows that items which can be easily identified when presented alone are lost in a crowded display. The ability to focus on targets in a crowded environment varies enormously across individuals, with professional athletes showing outstanding skills. Deficits in this kind of attention have serious implications for everyday life: Elderly people often show a marked narrowing of spatial attention, producing a kind of tunnel vision that poses risks to their safety in driving or walking in traffic. Other age-related changes may occur in the flexibility of switching attention, in the rate of scanning, and in the speed of conscious access to perceptual information. Research on attention in dynamic displays has direct implications for the design of work environments, car dashboards, intersection signaling, and computer displays, to name just a few examples.

Future Directions in Research on Attention

Improved Selection and Training — Basic research on attention has the potential to improve employment selection for hazardous positions. Individuals differ considerably in their ability to deploy attention efficiently. However, standard visual tests do not reveal an individual's degree of attentional access. Among other things, this means that attentional factors are not evaluated in candidates for attentionally-demanding jobs, such as driving, piloting airplanes, or running air traffic control. For example, pilots are routinely given visual tests but not tests of attentional skills (although flight simulators indirectly evaluate the influences of attention). The prevalence and importance of inattentional blindness (described above) underscore the need for tests to evaluate attentional skills for different tasks. Simple, quickly administered attention tasks could be used to meet this need. Research and tests on useful field of vision and on attentional switching are steps in this direction. Once in place, this type of screening should place better qualified operators in attention-demanding situations and should save lives and improve productivity. Research which monitors the expected improvements would validate these claims for essential changes to the way we license drivers, pilots, and others in control of hazardous situations.

[1]See "Cross-Cutting Issues" for additional discussion of neuroimaging and cognitive neuroscience.

Recollections of past experiences, general knowledge of facts and concepts, recognition of objects, learning of skills—all depend on our ability to acquire, retain, and retrieve information.... Basic behavioral researchers, employing advances in neuroimaging techniques, are unlocking the secrets behind the enormous power of memory in terms of the ability to learn, remember, and adapt knowledge to function in different contexts.

The Nature (and Fallibility) of Memory

What do we know, and when do we know it? These and other questions about memory are raised every day from the courtroom to the classroom, and they are being answered by psychologists in the laboratory.

Memory is critically important in our lives. Recollections of past experiences, general knowledge of facts and concepts, recognition of objects, learning of skills, all depend on our ability to acquire, retain, and retrieve information. Over the past decade, intensive study by research psychologists has advanced our understanding of the nature and basis of memory. We know substantially more about the parts of the brain involved in memory and how these parts work together in different memory systems. Basic behavioral researchers, employing advances in neuroimaging techniques, are unlocking the secrets behind the enormous power of memory in terms of the ability to learn, remember, and adapt knowledge to function in different contexts. We also are beginning to understand the factors that shape memory and its fallibility under various circumstances. Examples of recent advances in this area are presented below, along with important lines of inquiry that are likely future directions in research on memory.

The Nature of Memory Systems

Distinct Brain Systems in Memory — Recent collaborations between psychologists and neuroscientists have yielded some particularly noteworthy new insights. To take just one example: There is now a core of studies of healthy individuals, of patients with memory loss from damage in certain regions of the brain, and of nonhuman animals with lesions to specific brain structures that indicates that memory is composed of several distinct systems, each involving specific networks of brain regions. For instance, patients with damage to the hippocampus and related structures in the medial temporal lobes have great difficulty remembering specific events, but they can learn new skills in an entirely normal manner. In contrast, patients with damage to the basal ganglia show the opposite pattern; they have great difficulty learning new skills, but can remember events. What this and related research means is that we are closer to pinpointing where in the brain specific kinds of memories from specific kinds of experiences are created and reside.[1]

Working Memory — Other lines of research have highlighted the critical importance of a specialized system known as working memory, which is involved in the short-term, on-line retention of information used during various kinds of cognitive tasks. In addition to describing the components of the working memory system and characterizing its functions, this line of research has developed a solid foundation of findings that is beginning to find applications in everyday life. For example, a great deal of research has been carried out on a part of working memory known as the "phonological loop," which holds small amounts of speech-based information. Initially it was thought that the phonological loop was purely a temporary holding device, playing no role in long-term memory storage. However, studies of both cognitively intact individuals and brain-damaged patients have shown that the phonological loop plays an important role in long-term memory of new phonological information, such as learning new vocabulary or new languages. Developmental studies have shown that measures which indicate the operation of the phonological loop can be useful predictors of vocabulary acquisition. Research to develop and refine such measures has significant potential for applications in education and remedial care.

Blocking Traumatic Memory — Various studies have shown that retention of emotional experiences depends on a system distinct from other forms of memory. For example, cognitive studies have shown that when people view a videotape that includes both nonemotional and emotionally arousing events, their memory for the arousing events—for example, one that involved an injured child—is especially accurate. However, when given drugs (e.g., beta blockers) that interfere with the emotional memory system, they no longer show better memory for an emotionally arousing event, even though they perceive the event to be emotionally arousing. Related studies of brain-damaged patients and experimental animals have uncovered a specialized role for the part of the brain called the amygdala in memory for emotionally arousing experiences. This line of research has important implications for understanding, and possibly counteracting, the kinds of intrusive recollections that can plague survivors of emotionally traumatic events. For instance, it might be possible to administer beta blockers to emergency workers who deal with disasters such as fires, bombings, or other highly disturbing events that would be remembered vividly and intrusively.

[1] See "Cross-Cutting Issues" for additional discussion of neuroimaging in basic research in psychology.

The Fallibility of Memory

Despite the impressive feats and enormous power of our memory systems, memory is also curiously subject to distortions. The importance of understanding the fallibility of memory has been highlighted by controversies concerning the reliability of children's recollections and the accuracy of traumatic childhood memories recovered by adults in psychotherapy. Individuals have been sent to jail and families have been torn apart on the basis of memories of abusive incidents that, in some instances, may never have occurred. Likewise, the fallibility of memory is central in eyewitness identification; we need to develop techniques of questioning witnesses in a nonsuggestive manner so that the questioning does not contribute to inaccurate identification.

Memory Distortion: Forgetting the Source — Psychologists have been aware of memory's fallibility for years, but it is only recently that we have developed techniques for inducing high levels of memory distortion under controlled circumstances, which has allowed more systematic study of this phenomenon. For example, when preschool children are asked in weekly sessions to try to remember a fictitious incident, some will eventually develop a detailed false recollection of the event, even though they initially claim no memory for such an event. As the children are asked repeatedly about the fictitious event ("was there ever a time your finger was caught in a mousetrap and you had to be taken to the hospital?"), and think about or imagine it, the incident seems increasingly familiar to them. Some children interpret this sense of familiarity as evidence that the event occurred because they have forgotten the true source of the information—the repeated questions. This finding is underscored by other studies showing that young children often have difficulty remembering source information—whether they saw or imagined an event—which makes them prone to memory distortion.

Studies of adult memory also have implicated poor source recall as an important contributor to mistaken recollections. For instance, after having viewed a videotape of a simple event, volunteer adults were given narratives that contained inaccurate information about what had happened in the original event. When asked to remember the event from the videotape, volunteers were explicitly warned that all of the information in the narrative was false and should not be produced on the test. Despite these explicit instructions, however, volunteers still sometimes provided information from the narrative—something they would have done only if they had forgotten the source of the information.

In a related example, research participants were shown a series of famous names (e.g., Ronald Reagan) and nonfamous names (e.g., Sebastian Weisdorf). When they were shown some of the same names several minutes later and asked to judge whether they were famous, people rarely claimed that a nonfamous name was famous. But when tested the next day, they were significantly more likely to claim that nonfamous names were famous. The nonfamous names seemed familiar, but the participants had forgotten that they had encountered the names a day earlier. Having failed to remember the critical source information, they mistakenly attributed the familiarity of the nonfamous names to an incorrect source.

Other False Memory Effects — Other kinds of false memory effects have also been documented recently. For example, it has been shown that studying a list of semantically related words (e.g., candy, sour, sugar, good, tooth, taste) can produce extraordinarily high levels of false recollections of strongly associated words that were never presented (e.g., "sweet" in this case). Experimental participants claim with high confidence that they previously studied "sweet" about as frequently (70-80% of test trials) as they remember words that actually were presented, such as "taste."

Future Research: The Physiological Basis of False Recollections

With the kinds of studies described above, we are beginning to understand the fallibility of memory. But much remains to be learned about psychological aspects of memory distortions, and theories that attempt to explain these phenomena are just beginning to be developed. To take just one area—the physiological basis of false recollections—studies are starting to examine memory distortions in neurological patients using both traditional psychological techniques and brain-imaging techniques. But much more basic research is needed to examine systematically the brain processes and systems responsible for the fallibility of memory. For example, little is known about individual differences in susceptibility to false recollections and how those differences are related to underlying brain processes. Yet these differences could be critically important for everyday manifestations of memory distortion that have significant human capital implications.

This issue could be pursued with newly developed techniques for analyzing data from brain-imaging studies. Until recently, studies of true and false memories that used brain-imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have been severely restricted because the inherent limitations of these technologies have required researchers to analyze data collapsed across blocks of trials; that is, it has not been possible to compare brain activity for correct and incorrect trials, or for events that subjects say they remember and events that subjects say they do not remember. Now, new techniques in the analysis of fMRI data make it possible to compare and contrast event-related brain activity. These new techniques should make it possible to develop a much more accurate picture of what goes on in the brain when a person falsely (or correctly) claims to recall a past event. By correlating brain activity during true and false recollections with behavioral measures of these phenomena across individuals, we may be better able to understand why some people are more or less prone to memory distortions.

Social Cognition and Stereotyping

Harmful and erroneous first impressions of others can occur unconsciously, and can be powerful influences in the course of social relations. As experiments in social cognition have shown, getting rid of these first impressions isn't easy.

Researchers in social cognition study behavior by investigating the information processing mechanisms (memory, perception, judgment) that enable individuals to function in a social world. This area of basic social psychology has provided a rich empirical and theoretical understanding of the ordinary factors that influence the perceptions and impressions we form of others, and the influence of such impressions on our view of others and on social relations. Much of the research in this area has focused on questions of how information about individual persons and social groups is selected, encoded, and stored in memory, and how such processes are influenced by prior knowledge, social experience, and social motives.

Perception of another individual begins with an act of categorization—placing a person somewhere within the observer's prior knowledge of general social categories and person types. Research in the area of social cognition indicates that this initial stage of impression formation has an important impact on how additional information about that individual is processed and organized in memory. First impressions really are important, but for different reasons than might otherwise be assumed. Although situations, prior expectations, and conscious thought all have some influence on what category of information is triggered at the outset, there is convincing evidence that categorization on the basis of sex and race (and the activation of associated stereotypes in those categories) occurs prior to conscious awareness, involving information processing and interpretation that are not subject to conscious, controlled judgment and decision making.

Based on research about mental control and the paradoxical effects of attempts to consciously suppress unwanted thoughts, recent experiments have demonstrated a "boomerang" effect in which stereotypes become more (rather than less) accessible following attempts at suppression. These findings, along with experimental research on implicit cognition and automatic activation, suggest that efforts to change deeply ingrained and culturally overlearned stereotypes must go beyond programs aimed at changing conscious attitudes and beliefs. Instead, the underlying cognitive structure that determines the relative importance and accessibility of alternative social categories must be targeted for change. This requires basic research on how the effects of practice, repeated exposure, and competing category utilization can be used to produce long-term changes in automatic categorization and stereotype activation.

Recent research on the effects of social stereotyping has also turned attention from the perceiver to the perceived, investigating the consequences of widely held social stereotypes for members of stigmatized groups. Results of some particularly dramatic experiments in this arena have clear implications for human capital. These experiments demonstrate that performance on standardized aptitude tests can be significantly influenced by altering the salience of negative expectancies. For instance, men and women with a history of successful performance in mathematics were given a portion of the advanced Graduate Record Exam in mathematics under one of two instructional conditions. In one condition, the standard expectations of sex differences in performance were invoked—that women did not perform as well as men in math. In the other condition, the same test was introduced as being one for which no sex differences had been previously found. In the standard expectancy condition, women performed significantly less well than men with the same mathematics background. However, under the alternative instructions, the performance of the women significantly improved and was equal to or better than that of the men in the same instructional condition.

Given the profound implications of successful test performance for further opportunities and achievements in mathematics-related fields, these findings are significant in their own right. But we need further basic research to fully understand the mechanisms by which implicit expectations are transferred to testing outcomes, to determine what other domains of performance are influenced, and to explore the effectiveness of interventions to counter the self-fulfilling prophesy effects of pervasive social stereotypes.

Researchers in social cognition study behavior by investigating the information processing mechanisms (memory, perception, judgment) that enable individuals to function in a social world. This area of basic social psychology has provided a rich empirical and theoretical understanding of the ordinary factors that influence the perceptions and impressions we form of others, and the influence of such impressions on our view of others and on social relations.

Basic research on the cultural aspects of cognition adds to our understanding of human behavior and human thought by characterizing both what is universal in all cultures and what is shaped by things that vary from culture to culture. These issues are important even in the earliest stages of human cognitive development.

Culture and Cognition: Understanding Similarities and Differences

Cross-cultural research in cognition seeks to determine which psychological processes are universal and which are culturally determined, an increasingly important distinction for coping with a shrinking globe as well as for psychological insights into our own perceptions and thoughts about the world

Although many aspects of human development and behavior are universal, many others are socially constructed and socially maintained. Members of cultures, subcultures, and societies share language, history, and experiences that shape their belief systems, attitudes, perception, cognition, and behavior. Only by comparing attitudes and behavior across cultural groups can researchers determine how and how much cultural context affects these basic psychological processes.

In addition to increasing our understanding of basic psychological processes, cross-cultural research in cognition has obvious practical applications: The increased globalization of production, trade, and commerce calls for a better understanding of cultural differences in thinking about world economics. Environmental challenges to human well-being, such as global warming, depletion of the ozone layer, and pollution of oceans and rivers, all call for research that will increase international understanding and cooperation. Within our increasingly multicultural country, cross-cultural research is needed to reduce barriers and enhance communication among people from different backgrounds.

Research Findings in Culture and Cognition

Language Differences and Conceptualization—Basic research on the cultural aspects of cognition adds to our understanding of human behavior and human thought by characterizing both what is universal in all cultures and what is shaped by things that vary from culture to culture. These issues are important even in the earliest stages of human cognitive development. Recent research has shown that babies build a rich understanding of the world around them even before they begin to speak, and that their language acquisition is guided by expectancies about relations between language and the world. For example, young infants pay more attention to objects if the objects are named for them, and are more likely to perceive objects as forming a category when they are all given a common label. At a later age, in English, a word's syntactic subcategorization—noun versus adjective, count noun versus proper noun, count noun versus mass noun, transitive verb versus intransitive verb—influences the child's initial assumptions about the meaning of the word. For example, if the child hears, "That's a blicket," when the mother is pointing to an unusual implement embedded in an unusual substance, the child assumes "blicket" refers to the implement. But if the mother says, "There's some blicket," the child assumes it refers to the substance.

Languages differ dramatically in how they carve up the world in terms of syntax, and in how their lexicons are organized. To give one small example, in Italian, "spaghetti" is a plural count noun and Italians say "many spaghetti" when referring to a plate of spaghetti; in English, "spaghetti" is a mass noun. More important, many languages have no count/mass distinction, so the speakers of such languages are not in every instance indicating whether the entities of which they are speaking are individuated or not, or are singular or plural. Researchers are actively investigating how these kinds of language differences affect how different people conceptualize the world. That is, language doesn't just describe the world we live in; it may be a reason we see the world as we do. And we may see different worlds to the extent that we use language differently.

Prelinguistic Representation of Numbers — Another example of the way in which cross-cultural research can lead to fundamental psychological insights is seen in research in prelinguistic representations of numbers. Both animals and human babies observe and remember the number of objects in an array, the number of events in some situations, and so on. Animals have been shown to represent numbers as high as 35 to 50. But only some cultures have constructed an explicit counting sequence of integers, such as "1, 2, 3, 4, 5...." Recent research has shown that the prelinguistic representation of numbers is structured very differently from the culturally constructed "1, 2, 3, 4, 5...." Further, this research has shown that it is very difficult for both children and nonhuman primates to learn this culturally constructed system, very unlike how children learn spoken language. But after this system is learned, one's understanding of numbers is transformed in fundamental ways.

Understanding the Biological World — Another basic research question concerns universal versus culturally specific understandings of the biological world. Research has established that biological concepts are organized in terms of intuitive theories that influence patterns of reasoning. This has important educational implications. For example, children in the United States appear to bring to the classroom a concept of biology that is organized around human beings and does not differentiate between biology and psychology. To acquire scientific biology, the children cannot simply accumulate facts; they must undergo conceptual change.[1] Is this pattern of conceptual development universal, or does it vary in different cultural contexts or different patterns of contact with the natural world? Such questions can be answered only through comparative research. The answers to these questions have important implications for science education as well as other areas. For example, health practices may be closely linked to an understanding of biological processes such as how germs and viruses spread and grow.

Self-Concept and Cognition — Cross-cultural study also is proving to be critical in our understanding of the concept of "self" and the influence of the self-concept on other thinking and behavior. Although developmental studies suggest that some form of individual self-awareness is probably universal, cross-cultural research shows that the representation of the self has significant cross-cultural variation. The most important distinction is whether the self is defined as an autonomous individual (as in most Western cultures) or in terms of interrelationships and connections with others, as a part of a social group that is perceived as the functional social unit. Differences between individual and collective concepts of the self have been found to relate to differences in theories of causality about social events and outcomes, emotional reactions to members in one's own group versus members of other groups, and motivation to serve individual versus group interests.[2]

It is also becoming clear that concepts of individualism and collectivism vary not only across cultures, but within cultures as well. Further understanding of this basic distinction in the cognitive representation of self and others has important implications for the effectiveness of appeals to collective interests as a motivation for individual behavior and also for a better understanding of in-group favoritism and out-group prejudice.[3]

Decision Making: Risk and Uncertainty — Economic globalization raises questions concerning cultural differences in decision making. There is increasing evidence that cultural groups vary in the types of information they absorb and in their patterns of reasoning about objects, events, and other people. They may differ in their attention to the goals and satisfactions of individuals versus those of groups or collectives. Such differences seem to have implications for the level of risk taking a culture can sustain in its members. Evidence suggests that collectivism may result in implicit social insurance against catastrophic losses, effectively reducing risk levels for members of such cultures and allowing them to engage in economic ventures deemed too risky by members of individualist cultures.

Further research into the cultural determinants of attitudes towards uncertainty and risk taking is needed to achieve a better understanding of this important class of behaviors. Such understanding could come from a theoretical distinction between cases in which groups disagree on a course of action because they differ in their perceptions of the risks and cases in which the groups may agree on the risks but disagree on the appropriate risk-benefit trade-off. More accurate and comprehensive psychological theories of decision making under risk and uncertainty will have implications for a range of applications, from the structuring of contracts for multinational joint ventures to cross-cultural negotiations.[4]

Future Directions in Research in Culture and Cognition

Cross-cultural research is an interdisciplinary enterprise. Intellectual and methodological developments in several core disciplines have led to a renewed interest in the influences of culture. Detailed models of conceptual structure, decision-making processes, and inferential mechanisms allow for a better characterization of cultural differences in these areas. A more comprehensive modeling of social processes requires additional collaboration with other social and physical sciences.[5] Consider, for example, the question of how environmental change is interpreted within existing cultural models and values. Studies linking patterns of understanding of the natural world to agroforestry practice require not only anthropologists, linguists, and cognitive psychologists but also botanists, zoologists, and ecologists.

As with any interdisciplinary work, the most promising directions of research in culture and cognition are those with theoretical implications for each parent discipline, in this instance, psychology and anthropology. The general problem that animates all work on culture and cognition — namely, separating what is universal in human thought from what is culturally unique—is of central theoretical importance for both disciplines.

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[1]See "Developing Expertise" for related discussion.
[2]See "Social Coordination" for additional discussion of research on group interactions.
[3]See "Social Cognition and Stereotyping" for related discussion.
[4]See "Decision Making and Statistical Reasoning" for additional discussion of research on decision making.
[5]See "Cross-Cutting Issues" for additional discussion of modeling in basic research in psychology.

Learning in Infancy — Just as work in theoretical linguistics of a generation ago was shaped by the search for cross-linguistic universals, work in cognitive development is now being shaped by the description of several domains of thought that influence learning in infancy. These include the domain of physical reasoning, with the object as the central concept and mechanical causality as the central explanatory principle; the domain of intuitive psychology, with the person as the central concept and intentional causality as the central explanatory principle; and the domain of number, with the integer as the central concept and counting/adding as the initial operations. Rich knowledge of each of these domains emerges early in infancy, before language or culture has had much impact, and evidently, knowledge of each of these domains is part of our primate heritage. Methods now exist for cross-cultural explorations of the degree to which each of these core domains affects the way in which adult thought is structured, and the ways in which culture builds on and sometimes replaces the universal principles that determine these domains in early childhood. In addition, the effects of culture on infant cognitive development have been little explored, but this is an area that holds much promise.[1]

Understanding Kinship — Another promising direction in research on culture and cognition begins with a topic of central theoretical importance to the discipline of anthropology — kinship. Recent work in anthropology has demonstrated that the heavily biological concept of kinship so characteristic of American society and other Western societies is far from culturally universal. Kinship systems are fundamental social organizing devices in all cultures, so the fact that in many cultures kinship structures are not explicitly biological has been an important development in anthropological theory. At the same time, however, work on children's understanding of intuitive biology in the United States has demonstrated that by at least age seven, and in the absence of formal tutoring, children have a fairly robust understanding that bodily characteristics such as skin and eye color are determined before birth. Cross-cultural work merging these two research perspectives could focus on several fundamental issues: or is American children's understanding of biological inheritance a culture-specific reflection of adult American folk biology? Or is this early understanding a reflection of universal folk biological understanding that coexists with explicit symbolic cultural constructions uncovered by anthropologists? These and similar questions should be addressed in collaborative work between developmental and social psychologists and anthropologists.

> ***In addition to increasing our understanding of basic psychological processes, cross-cultural research in cognition has obvious practical applications: The increased globalization of production, trade, and commerce calls for a better understanding of cultural differences in thinking about world economics. Environmental challenges to human well-being, such as global warming, depletion of the ozone layer, and pollution of oceans and rivers, all call for research that will increase international understanding and cooperation.***

[1]See "Human Development" for additional discussion of developmental research.

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Emotions penetrate the deepest recesses of human existence. They guide, enrich, and ennoble life and they provide meaning to everyday existence. They can be both an essential ingredient for—and an overwhelming obstacle to—realizing human potential. Emotions also promote behaviors that protect life. Given their evolutionary heritage and daily currency, it is little wonder that emotions have preoccupied humans throughout recorded history.

Emotions: The Basis of Human Nature

Beyond satisfying our own curiosity about these complex and often-mysterious behaviors, basic research on emotions is critical to understanding the role of emotion in physical and mental health, violence, decision making, memory, and virtually every other aspect of human life.

Fundamentally, emotions, attitudes, and moods are the manifestations of evaluative or "affective" processes—the mechanisms by which organisms distinguish hostile from hospitable environments, something that is done by all species. More broadly, emotions penetrate the deepest recesses of human existence. They guide, enrich, and ennoble life, and they provide meaning to everyday existence. They can be both an essential ingredient for and an overwhelming obstacle to realizing human potential. Emotions also promote behaviors that protect life. Given their evolutionary heritage and daily currency, it is little wonder that emotions have preoccupied humans throughout recorded history. While they are behavioral and psychological in nature, there is little doubt that emotions also are biologically rooted and culturally molded. Basic research in emotions has yielded an impressive wealth of information that has significant methodological and conceptual implications.

Research Findings: Emotion and System Synchronization

Perhaps the most basic and widely accepted divisions among psychological processes are the distinctions among action, cognition, and emotion. The functions served by the first two are well-documented in psychological research. However, there is far less consensus concerning the functional or adaptive value of emotion, particularly with respect to negative emotions. Positive emotions may not be necessary in the same way that mental representations and overt behavior are, but because they reflect the phenomenal counterpart to rewarding and desired experiences, their occurrence is not particularly difficult to understand. In contrast, the role of negative emotion in human experience is not self-evident and over the years has been the object of a significant amount of theoretical and empirical attention in basic research in psychology.

Several lines of classic and contemporary research suggest that negative emotions play a primary role in calibrating psychological systems. The idea is that the disruption of personal and interpersonal processes generates negative emotion, which signals to the system in question that readjustment is called for in some relevant control mechanisms. The greater the disruption, the stronger the signal and corresponding negative affect.

From this perspective, negative emotion plays a vital role in mental and behavioral adjustment. Were it not for negative emotion, psychological systems would not adapt to changing circumstances or evolve to accommodate increasing demands and complexities in the physical and interpersonal environment. This view of emotion has been developed for different phenomena, including the mental control of action and self-concept, as discussed below.

Emotion and Mind-Action Calibration—Considerable research has shown that mental representations are highly dynamic and have a reciprocal relation with overt behavior. People think and form judgments in the process of understanding and controlling their behavior. In turn, the results of behavior provide feedback regarding the quality and usefulness of one's representations and judgments. Without these "reality checks", the mental system has the potential for getting caught in a self-reinforcing loop in which increasingly out-of-touch thoughts go unchallenged and uncorrected.

Emotion plays a pivotal role in this feedback loop by signaling when mind and action are not well calibrated. This role is consistent with theories suggesting that negative emotion commonly results from the interruption of goal-directed action. Efficient functioning requires a high state of coherence in the mind-action system. A breakdown in this coherence, whether caused by external disruption or faulty mental representations, signals the need for readjustment in the system. Negative emotions provide this signaling function and inhibit current action until control mechanisms are able to recalibrate mind and action. When calibration is regained, affect again comes into the picture, this time signaling that the elements of one's mental representation are well-synchronized and attuned to the demands of effective performance.

Emotion and Self-Control — The capacity for self-control is widely recognized as one of the defining characteristics of human nature. Broadly defined, the capacity for self-control means that people can inhibit the expression of their thoughts, feelings, and actions, and can terminate these expressions once they are initiated and have yet to run their course. Self-control also is reflected in the capacity to initiate and maintain courses of action that run counter to one's immediate personal desires and impulses. The exercise of self-control implies the existence of another process beyond those being controlled. This meta-control process is commonly discussed in terms of self-awareness.

Theoretical accounts of self-awareness generally agree that it is associated with heightened sensitivity to perceived discrepancies between one's behavior and a salient personal or social standard of appropriateness or desirability. Discrepancies between self-standards and behavior are experienced physiologically as aversive arousal and phenomenologically as negative affect. The greater the deviation from whatever standard is salient, the greater the arousal and negative affect.

In contemporary theory and research, the negative affect associated with discrepancies between self-concept and action is discussed under the category of "self-conscious emotions" and is said to include such uniquely human states as embarrassment, guilt, and shame. In reducing discrepancies between self-concept standards and behavior, people are said to exercise self-control over their impulses, desires, unacceptable feelings, and immoral thoughts. From this perspective, self-awareness is a vivid and unpleasant signal that one's current state is not well coordinated with a relevant representation.

Contemporary research is exploring the variety of standards available for self-control and attempting to place them in a conceptual taxonomy. Various types of self-standards have already been identified, and the discrepancies associated with them have been mapped onto qualitatively distinct affective states. Research in this vein is also beginning to explore the potential for simultaneous activation of different standards and the consequences of such conflict for subsequent thought, emotion, and behavior. There is also emerging evidence that the stability of self-standards represents an important dimension of individual variation. People who lack a stable, integrated sense of self may also lack internalized frames of reference for self-control. Like those with a well-structured sense of self, people lacking internalized frames inhibit behavior likely to produce negative emotion, but the standard for such affect resides in the real or anticipated reactions of people they interact with or wish to please.

Future Directions in Research in Emotion

Emotions, Attitudes, and Moods—Different manifestations of evaluative processes have been conceptualized as falling along a bipolar (positive/negative) dimension. However, this is changing as research in areas ranging from social psychology to psychophysiology to neuroscience suggests that this bipolar dimension may be insufficient to portray fully the positive and negative evaluative processes underlying attitudes and emotions. One implication of this area of work is that human potential may be fostered by adopting a more comprehensive framework within which to view affective processes and the consequent behaviors and feeling states.

The question is not whether positive and negative evaluative processes are reciprocally activated, but rather under what conditions they are reciprocally, nonreciprocally, or independently activated. Research on the separability of positive and negative evaluative processes requires both a rethinking of the conditions and measures that have dominated the field (e.g., contrasts between positive and negative states; bipolar scales or coding schemes) and an integrative approach that treats reportable feeling states or motivated behaviors as outcomes.

To address this question, researchers need methods that make it possible to manipulate or measure the activation of positive evaluative processes and the activation of negative evaluative processes. Among the measures that are contributing to a better understanding of affective processes are unipolar ratings, facial expressive movements, electroencephalograms (EEG) and event-related potentials, functional brain imaging (fMRI), and approach/withdrawal behaviors. Studies of positive and negative affective processes in animals and patients with specific neural lesions provide an important source of information on possible mechanisms involved in affective processes.

Other important new areas of research in emotion include studies of the cultural determinants of emotional experience and expression, the cognitive operations underlying positive and negative affect, the effects of positive and negative emotions on the immune system, as well as neurobiological studies in animals dedicated to clarifying the neurochemistry and neuroanatomy of brain circuits that serve emotional processes.

Decision Making and Statistical Reasoning

For better or for worse, people make decisions that don't always fit into a rational scientific framework or sound statistical analysis. Psychological research seeks to reduce bad decisions by developing ways to improve statistical reasoning.

Psychology brings a unique and important perspective to the study of decision making, focusing on behavioral processes that are complex and often seem irrational. This approach is in contrast to other disciplines which assume that individual behavior is highly regular. Examples of deviations from fully rational behavior abound in everyday decision making. Many people do not save enough money for their own retirement; many do not make rational decisions about smoking or speeding; and in an era of AIDS, too many young people engage in risky sex. Understanding the basis of these seemingly irrational decisions may enable better personal and policy decisions in health, finance, the workplace, the environment, and other areas where statistical information is of central concern.

Reducing errors in statistical reasoning is an important goal because of the central role that statistics plays in critical individual and social decisions in health care, education, criminal justice, economics, the military, science, the environment, and many other areas. Professionals who should be concerned with the accuracy of statistical reasoning include lawyers, physicians, investment counselors, military officers, and scientists. They must assimilate statistical information and convey it effectively to juries, patients, investors, commanders, other scientists, or public policymakers. Statistical reasoning increasingly is called for in a variety of situations: People are confronted with new information about risk factors and statistics on the effects of preventive behavior on health. Juries are asked to make decisions based on evidence that speaks to innocence or guilt in terms of very small probabilities. Military commanders regularly make life-and-death decisions under extreme time pressure with incomplete and often inconsistent information.

Research Findings in Decision Making and Statistical Reasoning

In the past two decades, we have seen the development of a rich body of basic research in decision making. In particular, psychologists have conducted a significant amount of research on statistically based reasoning. This research has uncovered many basic phenomena, among which are the following:

- Instead of following systematic statistical reasoning, people often use other methods, including reasoning by prototypes, causal relations, and past cases.
- People make different decisions when the outcomes of alternatives are framed as potential losses compared with when the outcomes of the same alternatives are framed as potential gains. For example, when people evaluate an expensive road change, it matters whether it is formulated in terms of lives saved if the change is made or lives lost if it is not.
- People reason about many probabilistic events more accurately when such events are conveyed in terms of frequency rather than in terms of probability.
- People exhibit errors of various types in intuitive prediction, including a surprising insensitivity to sample size, distorting and misinterpreting correlations, or simply failing to understand concepts like regression.
- People tend to misunderstand conditional probabilities when making decisions (e.g., equating the probability of being obese, given breast cancer, with the probability of having breast cancer, given obesity).
- People reach overly strong conclusions from incomplete data. If some criterion measure is used to select people for a task, it is impossible to know how good that measure is when the only available data are the successes and failures of the people actually selected. Often there are few or no data about the candidates rejected, even though these data are crucial in evaluating the criterion. For example, we don't know if low Scholastic Aptitude Test scores in fact signal poor performance at top colleges, because few low scorers are admitted.
- People tend to assume that effects are independent rather than interdependent or correlated. For example, both smoking and exposure to certain asbestos materials are linked to lung cancer, but their joint effect is far worse than if these were independent contributors to the disease, a fact that many people do not appreciate.

Future Directions in Research in Decision Making and Statistical Reasoning

There are a number of critical topics to be addressed in basic research in the area of decision making and statistical reasoning. We still do not understand fundamental components of decision-making processes. For example, everyone formulates decisions in terms of gains and losses and in terms of risks. How do decision makers establish the reference points by which they assess gains and losses? How does evaluation of alteratives translate into choices, and when does the translation fail? How are the potential consequences of decisions integrated with their probabilities? Why, when computing probabilities that are conditional on some event, do people sometimes—but not always—overlook the overall event probability? For example, people fail to consider the low base rate of HIV in the U.S. population when considering the chances that they actually have HIV, given a positive test result. As a result they will be much more alarmed by a first positive HIV test than is warranted. (In research on statistical reasoning, this is referred to as base rate neglect.)

To date, efforts to improve the communication and teaching of statistical ideas have not produced large-scale improvements in people's handling of fairly ordinary statistical problems. The goal of learning statistical reasoning should be to develop better statistical "instincts," not just knowledge of particular statistical procedures. An important related question should be addressed by research: Is there an optimal age to learn statistical reasoning or decision-making techniques?

Several other basic research questions in decision making and statistical reasoning are discussed below.

Contexts of Decision Making — In order to understand the evolution of decision making, we need more research on how decisions are shaped by the broader ecology in which they are made. Consideration of the context of decisions will often result in a broader definition of the variables that a decision maker is trying to maximize. For example, foraging animals and insects sometimes display behaviors that appear to conflict with maximizing benefits. Bees do not return indefinitely to the same patch of flowers to find pollen, even though according to certain optimal theories an organism should attend exclusively to the schedule that provides the higher payoff. But in many environments, payoffs do not remain constant, because resources are depleted. Thus, it pays animals to sample food sources other than the one with the highest payoff schedule to (a) avoid depletion of that source and (b) test for changes in payoff schedules at other sources. How do animals acquire an awareness of these kinds of environmental constraints? What are the underlying mechanisms of foraging, a behavior in which an organism exhibits probabilistic responses to certain payoffs—seemingly an irrational behavior that is understandable in a broader context?

Similarly, the social or cultural context within which decisions are made is often significant. For example, how does social accountability affect decisions? How is decision making distributed across individuals? When is decision making rule-based, and when is it role-based? Considerable empirical research exists on these and other questions about the social context of decision making, and these data should be incorporated into the major decision theories and their applications in business and economics.

Emotion and Reasoning — Another area warranting additional basic research is the affective component of decision making. Many decisions are made under conditions of high stress and affect levels. Basic research has shown that emotions have an undeniable and many times positive role in attitudes, decision making, and behavior.[1] This contradicts popular wisdom, in which the classic assumptions are that emotion wreaks havoc on human rationality and that dispassionate analysis optimizes decision making. More research is needed in order to understand the emotional component of decision making, and how emotions affect what information is extracted and used in reasoning.

Interdisciplinary Models of Decision Making — The study of decision making in psychology has strong ties with economics, management science, and statistics that date back to the 1950s. Complex mathematical models of decision making originated in economics and mathematical statistics at that time, but subsequently have been developed in a number of disciplines, including psychology. Historically, many of these models have had a highly rational quality, particularly those originating in economics and statistics. The assumptions of such models (which are called behavioral in psychology, and axiomatic in other disciplines) focus on relations — often trade-offs — among observable variables, such as consequences and their probabilities of arising, but not on relations among hypothesized, unobservable variables. Unobservable variables such as utilities and subjective probabilities are inferred from, not postulated by, models of observed behaviors.

Research psychologists have focused on the many instances in which human decision makers deviate from those rational assumptions and exhibit some form of "bounded rationality" or even irrational but somewhat reasonable behavior. Incorporating the empirical findings from this research, new and far more descriptive models that are based on modified behavioral assumptions have been developed. These newer models are influential to some degree in both economics and management science, although the interdisciplinary gulf remains large. In addition, some psychologists are attempting to devise various kinds of information processing models, including models based on neural nets and on nonlinear processes, to provide alternative accounts of the observed decision-making behavior.[2]

One very important area of research is concerned with models of various types of interaction, cooperation and competition among individual decision makers. This area includes the mathematically well-developed topic of game theory and experiments, by psychologists and some economists, aimed at testing the descriptive powers of such models. More interaction is needed among the disciplines, given the importance of game theory in economic analyses. Collaborative efforts in this area by management scientists, economists, psychologists, and statisticians will contribute to each of the disciplines and should be encouraged.

[1]See "Emotions" for additional discussion of research on emotions.
[2]See "Cross-Cutting Issues" for additional discussion of modeling in basic research in psychology.

Temporal Aspects of Decision Making — Time enters into decision making in several ways. One concerns the delays that occur in knowing the outcomes of decisions. Some decisions, such as consuming sweets or smoking, have both immediate hedonic rewards and future undesired consequences. Depending on how future consequences are discounted, people make different patterns of choice. Another way concerns decision making under time constraints. Much real-world decision making is described as putting out fires. How do decision makers evaluate alternative circumstances when time is of the essence? Only rarely has this aspect been incorporated in decision-making models.

Until recently, most of what we know in detail about temporal aspects of decision making came from the accumulated research on operant behavior in animals. But increasingly, researchers in human judgment and decision making are turning their attention to this crucial, if very difficult, aspect of decision making. The synthesis of existing information on the temporal aspects of decision making is an important next step in research in this area.

Neuroscience of Decision Making — Another potentially important but as yet largely unexplored area is the neuroscience of decision making, including interactions between affect and cognition. Imaging techniques such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) may permit us to track in some detail the flow and processing of information in the brain.[1] Such knowledge should contribute to the development of information processing accounts of decision making, which are currently less well developed than purely behavioral ones. Moreover, understanding the neuroscience may allow predictions not only about choices, but about the time to decide and the nature of the trade-off between choices and time, both of which are relevant to decision making under time stress.

Reducing errors in statistical reasoning is an important goal because of the central role that statistics plays in critical individual and social decisions in health care, education, criminal justice, economics, the military, science, the environment, and many other areas. Professionals who should be concerned with the accuracy of statistical reasoning include lawyers, physicians, investment counselors, military officers, and scientists. They must assimilate statistical information and convey it effectively to juries, patients, investors, commanders, other scientists, or public policy makers.

[1]See "Cross-Cutting Issues" for additional discussion of neuroimaging in basic research in psychology.

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A nation's most important human capital is its children. Human development is a protracted apprenticeship — up to 20 years or even more in our technological society — and it can go wrong from its earliest moments: Poor nutrition or drugs during fetal development, unstable emotional environment during the crucial early years, and failures of social institutions (including family, school, and government) all affect psychological development.

Human Development: The Origins of Behavior

Understanding how psychological processes develop is essential to understanding how we function throughout our lives. Basic research in this area has shown that many of these processes are up and running at birth and even before.

Developmental research is discussed throughout this report, and it is a central topic in basic research in psychology more generally. Scientifically, it is difficult to say we understand human thinking, perception, attention, or linguistic, social, or cultural competence if we don't understand how these competencies develop. As has been recognized at least since the time of the Greek philosophers, studies of development inform many of our theories of the adult. However, achieving an understanding of human development is of far more than intrinsic scientific importance: A nation's most important human capital is its children. Human development is a protracted apprenticeship — up to 20 years or even more in our technological society — and it can go wrong from its earliest moments: Poor nutrition or drugs during fetal development, unstable emotional environment during the crucial early years, and failures of social institutions (including family, school, and government) all affect psychological development. It is crucial to understand the mechanisms by which confident, productive, creative, competent young adults are formed, so that we can do everything possible to help the apprentice make the most of his or her human capital.

Research Findings in Human Development

Advances in knowledge and advances in methodology go hand in hand in all areas of science. The study of infant development is no exception; researchers are finding that complex learning begins dramatically earlier than previously realized, some of it at birth or even before. For example, even the youngest infants control what they look at and whether or not they will suck on a nipple; these simple facts allow psychologists to study the earliest stages of development. Infants prefer to look at something than at nothing, so one can study perceptual thresholds. Infants can use their looking or sucking to control what they will hear, so one can study what sounds they discriminate. Infants get bored if shown the same thing over and over again, so one can study what things in the world they see as similar to each other. And infants look longer at the outcomes of simple magic tricks than at the outcomes of ordinary events, so one can study their expectations of the physical and social worlds. Recently, recordings of patterns of brain activity have been added to the methodological arsenal available to researchers.

Twenty-five years of data from this combination of methods has established, among other things, that complex learning begins very early, that individual differences among people are evident or established early, that there are critical periods of learning for many domains of knowledge, and that not all learning is alike. Some of these findings are sketched below:

Knowledge Before Birth — Newborns come into the world as sophisticated learning devices, with a huge "leg up" on the problem of language acquisition and the problem of learning about the physical and social worlds. For example, infants are born with some sort of knowledge of what a human face looks like, and can match a parent's facial gesture with the corresponding one of their own. They learn to recognize their own mother's faces within hours. Learning actually begins in the womb; newborn infants recognize their own mother's voices and discriminate their own language from others on the basis of patterns heard before they were born.

For example, at birth or soon after, infants are able to discriminate any pair of consonants or vowels that languages of the world use contrastively. That is, babies hearing only Japanese can hear the difference between *r* and *l*, just as well as can babies hearing only English. However, with exposure to a single language, distinctions not made in that language are gradually lost. By six months an infant has learned his or her own language's vowel structure, and by 10 months an infant has begun to develop native categories for consonants. That is, by 10 months Japanese babies, just like Japanese adults, no longer discriminate *r* from *l*.

Early Individual Differences — Individual differences in sensitivity to stimulation are measurable early in infancy and persist through life. These early developing differences may become stable differences in temperament. For example, shyness in school-age children can be predicted from such measures at 2 months of age. Differences in infants' encoding speed in looking-time studies predicts a substantial proportion of IQ in school-aged children. Or to give another, more disturbing example, certain aspects of social/cognitive development in infancy (poor gaze and point following, joint attention, and pretend play) predict autism in the older child.

Such findings open entire new areas of research on the factors that drive human development and the effects of interventions early in infancy.

Critical Periods for Learning — Although infants have begun to learn the speech patterns of their own language before 10 months of age, young children maintain the ability to learn the speech patterns of other languages perfectly. Around puberty, this ability is greatly diminished. Most (but not all) people are unable to learn a new language without an accent if exposed to it after puberty, even if they speak it for decades thereafter. Even more surprisingly, the same advantage to early learning applies to the syntax of natural languages. Late learners never master fully the syntactic rules of languages to which they are exposed after puberty, even if this is their first language (as is the case with some deaf people first exposed to sign language late in life). This is true even if they speak it for decades and are able to express the most complicated ideas in it.

Similar advantages for early learning have been documented in many domains: sports, music, and chess, for example. The educational implications of this research are clear.

Not All Learning Is Alike — A remarkable characteristic of language learning, particularly given the complexity of language, is that language is learned universally, without explicit instruction, by all children who are exposed to it. This universality is not mirrored in acquisition of reading, writing, fractions, scientific concepts, or a host of other socially important, culturally constructed forms of knowledge. Take reading and writing as an example: Whereas the spoken language is an evolutionary achievement of the human species, writing is an invention used by only some human cultures. Invention of alphabetic writing was a particularly rare achievement; it may have occurred just once in human history. The same is true for many aspects of mathematical and scientific knowledge.

Understanding the structure and acquisition of expertise in such culturally constructed domains of knowledge is an active area of research.[1] With respect to reading, research in psychology in three domains—skilled word recognition, prerequisites for learning to read, and sources of reading failure—has progressed considerably. For example, research over the past 30 years has shown that differences in reading proficiency may be linked to differences in how children access phonological information when they read. Children's knowledge of spelling-sound correspondences predicts their word-reading speed. In turn, word-reading speed predicts text comprehension, presumably because reading is faster when it takes less conscious effort, and when effort is freed from word decoding, it can be devoted to comprehension.

Understanding that letters map with considerable consistency onto phonological segments requires an awareness that words are composed of distinct phonological segments. Very few children develop such awareness spontaneously. (Indeed, illiterate adults lack phonological awareness.) Research has shown that the child's level of phonological awareness on entering school is the single strongest predictor of success in learning to read for beginning readers of English, Swedish, French, Italian, Russian, and Spanish, the languages studied to date. Another study has reported a very high correlation between joint measures of children's meta-linguistic awareness of words and phonemes in the first grade and measures of reading achievement in grade 6. Such research findings have important implications for the teaching of reading. More generally, detailed psychological and computational models of learning have been constructed for many different domains of cognitive and social development. In each case there are important lessons for improving the apprenticeship of childhood.

Future Directions in Research on Human Development

The study of human development must proceed at many different levels, from the biological to the cultural. Thus, this work is highly interdisciplinary. At the biological level, we must integrate our understanding of behavioral development with evolutionary considerations and considerations of brain development. With respect to evolutionary considerations, new techniques for studying the infant's spontaneous representations of the world are just beginning to be adapted for the study of another class of non-linguistic organism— adult non-human primates, both in the wild and in the laboratory. This research opens up an extremely promising arena of comparative research that can be brought to bear on the evolution of mind, language, and the specialized learning devices that give infants a head start with respect to some domains of knowledge. With respect to brain development, imaging techniques (evoked potentials can be reliably measured from young infants, and magnetic resonance imaging (fMRI) data have been obtained from children as young as five or six), neuroanatomical studies, and work on memory and attention in primates have laid the groundwork for fruitful future collaborative work on the underlying neural mechanisms involved in perceptual, linguistic, and cognitive development.

At the computational level, we need detailed models of the mental representations that may be involved in observed competencies. The exploration of classes of cognitive architectures is an active area of research, with learning one of its central domains. This work is beginning to shape our understanding of the learning that constitutes normal development. The field is ripe for integrative work.

Equally important, the social policy implications from knowledge gained through the past 25 years of research have just barely begun to be realized. Here, too, the field is ripe for important interdisciplinary work, particularly in areas such as education, welfare policy, and psychology and law.

[1]See "Developing Expertise" for related discussion.

Developing Expertise: Research in Learning

Nowhere is the issue of human capital more important than in education. Research on how people learn about specific substantive domains is increasing our understanding of how expertise is developed and how it might be taught to someone else.

A major role of the education system is to increase the student's level of expertise in a number of domains, such as English, arithmetic, algebra, geometry, basic physics and chemistry, history, and other subjects. Less explicitly, the education system is expected to increase student expertise in a variety of socially and politically important ways, such as by providing some grasp of how various political and legal systems work, or of the interplay of environmental variables. Depending on many things, such as their individual interests, differential abilities, and socioeconomic status, students develop varying levels of expertise in different areas.

Perhaps surprisingly, what constitutes expertise is far less apparent than is widely believed. Research, much of it from cognitive psychology, has been centered on the exact nature of expertise in an intellectual domain and on how to design instruction to achieve expertise. These efforts have focused on three major topics:

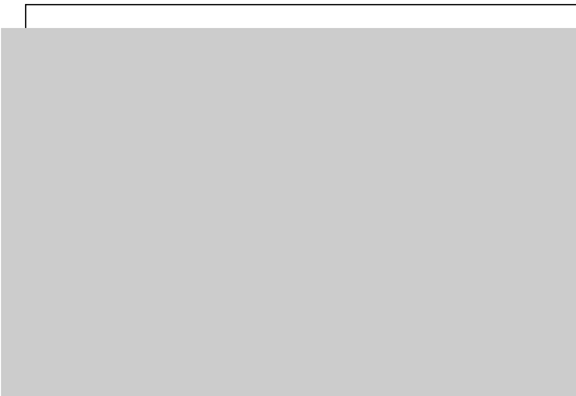
◆ **The Study of Non-Expert Models** — Children come to the educational system with intuitive, inferred models about many things. The educational difficulty is that these naive, erroneous models have considerable face validity. For example, in the area of play, many young children believe that if one drops something from a moving aircraft, it will fall in a straight line to the earth. Most have only a partial understanding of the more obvious conservation principles—that most things don't change much despite many transformations of length, width, temperature, etc. Because this is where education begins, one important line of research is seeking to understand these non-expert models.

◆ **The Study of Expertise** — In the study of individual expertise, the following questions arise: (a) Who is an expert? How can we distinguish experts from those who are non-expert? (b) What does a particular individual know about a particular domain? How can we find this out? (c) What is the structure of a particular domain of knowledge? How is expertise organized?

◆ **Learning and Teaching** — Compared with the knowledge state of an expert, the naive or untutored knowledge state can be incomplete or erroneous or, most likely, both. How students initially conceptualize a target domain is important information for a teacher or a curriculum designer. As the naive and expert knowledge states both become better understood, the question is how to get from the former to the latter in ways that can be adjusted to individual differences in the students, to teachers' limitations, and to various modes of instruction, including classroom discussions, lectures, demonstrations, and individual tutoring (usually by computer).

Achievements in Research on Expertise

Intuitive Mental Models — Great strides have been made in identifying the intuitive, naive, untutored ways in which children and adults understand and interpret concepts in at least the following basic areas: numbers and quantity, physical objects and processes, causality, and biology and life. Some of the earliest and best known work along these lines was done by the famed Swiss developmental psychologist Jean Piaget. For example, Piaget's famous observation that young children judge that the weight of a



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ball of clay can be changed by flattening the ball into a pancake reflects wide-reaching differences between children's and adults' conceptualization of the material world. In addition, some relatively recent progress concerns how people think and reason about complex issues, such as population growth and global warming, that require knowledge of several of the basic areas listed above. Through the use of structured interviews and other approaches designed to reveal individual mental models, we have a much clearer idea than we did a decade ago of the nature of these intuitive models as well as the misunderstandings that must be overcome and the new knowledge that must be acquired. This area of research should be encouraged in order for us to gain a more complete understanding of individuals' intuitive mental models, a necessary first step in any effort to modify attitudes or behavior.

Models of Domains — Experts can be expert without being able to explain very well the nature of their expertise. This is a central problem in the development of expert computer systems as well as in many educational situations. For example, many of us encounter it when trying to learn a new motor skill, such as tennis, golf, or flying. Each expert has a way of talking about and demonstrating the skill. In these situations, a major role of the expert seems to be to provide feedback about performance rather than information to promote expertise. However, for the most structured domains—mathematical topics and basic physical sciences—research has led to progress in inferring the nature of the structure(s) that experts know. Having models of expertise in these domains is an important element in understanding not only how expertise is developed, but how it is taught to someone else.

Developing Problem-Solving Skills — Advances in our understanding of naive and expert models of domains have helped investigators achieve significant understanding of the strategies for moving from one knowledge state to another more complete one. Such strategies have been most successful in the content areas of mathematics and elementary physics. For example, explicit attention to students' qualitative understanding of the concepts of mechanics facilitates teaching them how to solve quantitative physics problems. So too does engaging students in building and evaluating alternative representational schemes and models of the phenomena. These results are being put to use in numerous ways in mathematics and science education. Curricula have been designed to teach strategies that draw on what we know of children's intuitive understanding of mathematics and science. In addition, curricula in teacher education are increasingly emphasizing an understanding of students' patterns of thinking and reasoning. Similarly, some computer-based tutoring systems draw on these models of successful problem solving. Others are based on models that have been inferred from masses of test data for the domain being taught. In these instances, student performance is evaluated in relation to such models in order to determine the nature of the feedback that is needed, whether to repeat earlier topics that seem inadequately understood, and what new topics to take up. These two approaches differ from one another in how the domain is modeled and in their assumptions about learning.

Future Opportunities in Research on Expertise

Continuation of Current Directions — Even with the advances that have occurred, we remain far from having achieved a full understanding, even in the most structured domains, of naive models, expert models, and how to achieve the latter. Given the importance of expertise in education and the development of human capital, this research needs to be pursued vigorously. In addition, emphasis should be placed on applying the findings of research on expertise, at least on an experimental basis. Such efforts should be carefully evaluated. We need to know if problems result from faulty understanding of domains and processes of learning (e.g., student motivation), from distortions in the application, or from inadequate teacher training. In less structured domains, we have even less understanding, but an equally clear need for research. For example, in the area of development, of both spoken and written language, there is great controversy over methods of instruction, which underscores the need for additional basic research of the kind described above. Other domains, such as history, geography, and biology, have received comparatively little attention.

This research is inherently interdisciplinary. To achieve progress, researchers must have input from experts in the domains being modeled. Although this may be an obvious point, achieving appropriate interaction can be difficult because of the significant differences in disciplinary cultures and vocabularies. Strategies must be developed for encouraging cooperation of experts in these important areas of study.

Theories of Domains — Intellectual domains are a way of partitioning the complexity of the world into more or less manageable pieces. These domains are in a sense defined by experts and such social institutions as professional societies and university departments, and the partitions are embodied in curricula and texts. The question is, do children come to the school system with a mental partitioning of domains that are even close to those they will be encountering?

To answer this and related questions, we need to develop theories of domain formation, to understand how the conceptual boundaries arise. One issue is the nature and role of metaconceptual understanding: When and why do people characterize what they know as forming a part of a domain? Does such structuring make a difference in their use of concepts and in their reasoning? Better understanding of these boundaries should help in teaching people how to jump domain barriers, which is required, for example, when learning to apply mathematical concepts to nonmathematical problems that arise in physics and engineering or to apply physics and chemistry to biological problems.

Social Coordination: Working in Groups

Reconciling our own needs and goals with those of our co-workers or neighbors involves complex social interactions, the mechanics of which are the subject of basic research that has the potential to improve group-level problem solving and productivity .

Most of the phenomena studied by psychologists are processes that take place at the level of the individual person. But human psychology is inevitably shaped by the fact that we are a social species, adapted to interdependent group living. Further, all of the knowledge, skills, or expertise required to accomplish complex tasks rarely reside within a single individual but instead are distributed among individuals who must work together to achieve common goals. How do individuals synchronize their internal states and actions in various kinds of groups? How does a group provide coherence and order for individual and collective action? These and similar questions are the focus of basic psychological research into the mechanisms of social coordination—that is, the coordination of behaviors among two or more people.

Among other things, this research is essential in understanding the dynamics of relationships in task-oriented groups. Such dynamics include the emergence of group norms, the development of specialization within a group, efficiency in problem-solving groups, the inhibition of individual impulse, diminished individual identity, group polarization, collective action, the emergence of cooperation, and social identity. One line of inquiry has been to develop theoretical models that can simulate the social coordination that takes place in groups. Another has been to identify group-level phenomena that are related to the processes of interpersonal coordination. Examples of findings in these areas are presented below.

Research Findings in Social Coordination

Group Coordination — One of the great puzzles of social psychology is how cooperative and altruistic behavior occurs against the backdrop of individual self-interest. In a social context, people's fates are clearly intertwined, but quite often the consequences of ignoring one's shared fate are neither recognized nor experienced directly. For instance, a farmer may be motivated to overgraze an area of land shared with other farmers. In the short run, this action provides the farmer an advantage over his or her neighbors. But in the long run, ignoring the finite nature of the resource and the shared fate among all the parties concerned will result in suffering not only for the neighbors but for that farmer as well. In research on how individuals cope with such social dilemmas, social psychologists have identified a variety of factors that determine whether individuals cooperate or compete with one another.

In recent years, social psychologists have also developed computer simulations to model the group-level consequences of different strategies in social dilemmas. Examples of strategies are "tit-for-tat" (the person begins by cooperating then repeats the last choice made by his or her partner); "win-cooperate, lose-defect" (the partner with the greater outcome cooperates, while the partner with the smaller outcome competes); and "win-stay, lose-shift" (partners who perceive their situation as winning maintain their current behavior, while those who perceive their situation as losing change their behavior). In general, the results of such simulations show relatively small groups tend to reach equilibrium fairly quickly, with the interactants converging on a particular choice. In relatively large groups, different behavioral choices tend to co-exist, and after a considerable period of time,

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each strategy leads to a specific proportion of cooperating individuals. Although these proportions are maintained at the group level, the individuals often continue to change their choices. Recent research has shown that in dilemma situations where it is easier to lose than to gain resources, there is a higher probability of cooperation at the group level. This suggests that cooperation may be easier to achieve in a society living under harsh conditions (e.g., scarce resources, external threats) than in a society experiencing well-being.

Polarization and Clustering — Computer simulations have produced identifiable patterns of distributions of beliefs and opinions in a social group. One promising approach uses models of cellular automata to simulate such group-level properties.[1] Two important phenomena in particular have been observed through the use of computer simulations of social coordination. One is that as a result of social interaction, the average attitude in the group tends to become more extreme in the direction of the prevailing attitude. This phenomenon, referred to as polarization, has also been observed in experimental research on group dynamics. The second phenomenon, referred to as clustering, is the tendency for different opinions to become segregated. Under this effect, opinions that are in a minority in global terms form a local majority. An intriguing implication of this finding is that when conditions in society change so that the minority opinion becomes more desirable, there may be a rapid social transition with the minority point of view suddenly becoming the position favored by the majority. The results of computer simulations documenting this scenario have recently been verified with empirical data from countries in Eastern Europe that experienced political and economic transitions after the collapse of the Communist empire.

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The use of computer simulations to model complex social processes is in its early stages. Although cellular automata have generated insight into the emergence of group- and societal-level phenomena, and although computer simulations are proving useful in modeling the dynamics of social coordination, it remains for future research to refine these models and test them in the context of other interpersonal and intergroup processes. In addition, the results of this work must be validated against empirical data concerning these processes. Only by developing the base of both empirical and simulation data are we likely to uncover the subtleties and complexities of social coordination.

Future Directions in Research: Combining Social Psychology and Cognitive Science

Basic research on group interactions has produced a significant body of scientific knowledge of the processes involved when groups of people are solving problems and making decisions. This knowledge can be extended in important new ways, using the concepts and empirical and analytical methods developed in cognitive science to investigate the underlying psychological processes involved in such things as how people handle information and how they use language. Combining these areas of research has the potential to expand greatly our scientific knowledge about the processes of problem solving, decision making, and reasoning, and our understanding of how people collaborate and how they interact with complex information systems.

Social Interaction and Information Processing — Fundamental advances can be achieved by combining the concepts and methods of studying social interaction in social psychology with the concepts and methods of studying information processing in cognitive science. One approach would be to analyze cognitive processes in individuals and extend these analyses to settings where people communicate with each other and interact with complex information systems. This research would focus on the information processing aspects of these activities, including how members of the group construe the problems to be solved and how they establish and agree on goals, and the plans and actions that are carried out to achieve them. (Some work of this type is already under way in research on organizational behavior.)

Another approach would focus on systems that involve groups of people interacting with information systems and other technological artifacts, such as the ground operations crew of an airline, a typical air traffic control center, or a physics laboratory group working together to solve a problem at a computer. In such studies, the focus would be on ways in which individual participants communicate and coordinate their actions with each other and with the incoming information to accomplish their work.

[1]See "Cross-Cutting Issues" for additional discussion of modeling in basic research in psychology.

Tools and technology are part of socially distributed cognitive systems, both as interactants and because instruction in their use requires social interaction. Recent research in this area has investigated how information is used and represented in various types of projects, such as constructing and using diagrams in designing software, interpreting results of physics experiments, or determining that a parking gate is about to become vacant for an incoming airplane. An important question to be addressed in interdisciplinary efforts by psychologists and engineers is: What properties of such distributed cognitive systems can be given to machines and which social properties must be retained by people in order for systems to work effectively?

Language in Social Processes — A particularly promising area where basic research in cognitive science and social psychology can be combined is in the study of language, since language is the primary means by which members of a group communicate and coordinate their actions. Typically, research on language in cognitive psychology focuses on the mind and the nature of the mental processes involved in language perception, comprehension, or production. However, another important line of research focuses outward, on the use of language in the public domain. Here, issues for basic research include such questions as:

- What are the principles by which people accomplish things in their conversations?
- What nonlinguistic sources of information support achievement of communicative aims?
- How do these nonlinguistic sources of information shape what speakers choose to say to achieve their aims?

Basic research has shown that in the context of coordinated or joint projects and other social situations, effective speech generally requires social coordination. Both the efficacy of language and its efficiency—how much information must be conveyed explicitly in order for a message to be understood—depend on variables that serve as common ground between participants in a joint project. Examples of common ground include shared language—even dialectal differences may decrease the efficacy of interchanges in a joint project—and culture.

Basic research on group interactions has produced a significant body of scientific knowledge of the processes involved when groups of people are solving problems and making decisions. This knowledge can be extended in important new ways, using the concepts and empirical and analytical methods developed in cognitive science to investigate the underlying psychological processes involved in such things as how people handle information and how they use language.

Another example of common ground is shared, culturally acquired understanding of the roles and expected behaviors of members of the group. Such understanding allows a joint project to be moved forward nonlinguistically because what is said is both highly efficient and highly efficacious. Conversely, speech produced in the context of a joint project will fail to communicate as intended when speakers misjudge the common ground they share with their participants. Basic research drawing from social psychology and cognitive science has the potential to lead to improved ways of communicating in task-oriented groups, thereby increasing group effectiveness.

Photo courtesy of Center for the Neurobiology of Learning and memory, Univ. of California-Irvine. John H. Ashe of the Univ. of California-Riverside (standing) is pictured with Norman Weinberger, of the Center for the Neurobiology of Learning and Memory at the Univ. of California-Irvine.

Cross Cutting Issues in Basic Psychological Research

As this report illustrates, basic research in psychology encompasses a diverse array of subjects. But central to all of these areas is the development of new experimental tools and methodologies that allow researchers to combine perspectives in fruitful new ways. Some of the major cross-cutting methodological developments and issues in the field are discussed below.

Modeling of Psychological Processes

Psychology, in attempting to characterize what are arguably some of the most complex phenomena in the natural sciences, has made some progress in developing mathematical, statistical, and computational models to help us understand a wide variety of phenomena, both individual and social. There have been significant modeling breakthroughs in virtually all subdisciplines, from brain function to group dynamics; in some subfields—such as vision and audition—modeling is central in almost all research, whereas in others—for example, the study of emotions—it is comparatively rare.

The types of models being explored in various subfields are quite varied. However, two broad distinctions, which are found in all modeling in the sciences, must be kept in mind. One distinction is whether the model is formulated solely in terms of observable variables or whether it postulates some form of unobserved substructure whose properties give rise to the observed behavior. This distinction is familiar in the physical sciences; for example, Newtonian and Einsteinian physics were cast in terms of the relations among macroscopic observables such as mass, length, and time, whereas the kinetic theory of gases and the particle models of the 20th century involve hypothetical structures that are designed to account for directly observable behavior. Both types of models are encountered within psychology, with the former often being described as behavioral and the latter going under various names, examples of which are information processing, connectionism, and cellular automata.

A second distinction is whether the model attempts to describe static or dynamic phenomena. Dynamic models always encompass the former as a special case, but they are almost always vastly more difficult to develop successfully.

All psychological modeling, even of the most basic psychological processes, faces two empirical realities that make model testing difficult: (1) Human (and animal) experience tends for the most part to be irreversible; and (2) despite much commonality, people exhibit substantial individual differences. The first reality means that we cannot in any simplistic way subject an individual repeatedly to the same experience and thereby get a detailed statistical description of what happens. The second means that we should not attempt in any simplistic way to average over individuals.

Outlined below are a few of the more prominent and promising approaches in the modeling of psychological and behavioral phenomena.

Static Process Models — Many widely used models, including factor analysis, multidimensional scaling, and ability-testing models, fall into this category. They hypothesize an underlying structure of some sort that is designed to explain the observed behavior. For example, in models used to measure abilities, an underlying attribute is postulated, people are assumed to vary in the amount of the ability they possess, and questions about a subject matter vary in the amount of ability needed to answer each question. The attribute is not directly observable. Research in this area, which draws heavily on modern computing power, is extensive. One recent version is a model that supposes the knowledge domain of elementary geometry can be represented as a family of knowledge states with a precedence structure which in essence says that before a student can be in one state he or she must be in one or another of several antecedent states. The task facing the researcher is to establish the details of the underlying knowledge state and to devise ways of determining where a student is in that state. As the static process model is perfected, it leads quite naturally into dynamic questions about the learning paths (see below).

Static Behavioral Models — Much of the modeling of decision-making processes is behavioral, in the sense that the models describe relations among observable behaviors. In these models, mathematics is used to formulate simple behavioral "laws" and derive from them other behaviors that can be expected from a particular individual. Sometimes these descriptions serve as the foundations for modeling more complex behavior, such as microeconomic phenomena.

Models of this type are common in psychophysics—the study of sensory variables such as loudness, pitch, brightness, chroma, the nature of sensory space, and the perception of motion. For example, spatial perception models attempt to describe which arrangements of point sources of light people perceive as equidistant even if they are not physically equidistant, or as forming parallel arrays when they are not actually parallel. From models of such data, the researcher attempts to derive the nature of perceptual geometry.

Typically, the laws describing a behavior either have no free parameters or very few, which contrasts sharply with the processing models, which typically abound in parameters that have to be estimated. Despite the simplicity of the postulates, quite complex behavior can result from static behavior models.

Dynamic Processing Models of Individual Behavior — Part of the cognitive revolution of the past 30 years has been the development of mathematical and computer models of internal information processing. These models typically entail a structure of information flow that begins with some challenge perceived by the person, followed by information gathering and retrieval from memory; then responses are made, followed by some form of feedback that affects information storage in the system. In many such models, issues that must be addressed concern what occurs in parallel and what occurs in series, whether or not processing capacity can be transferred from one part of the system to another, how information from various subsystems is combined in order to arrive at decisions, and exactly what is affected (and how) by information feedback.

Information processing models are generally of three major types:

- *Stochastic processes*, such as have been used in a number of probabalistic models of perception, learning, categorization, memory, response times, and psychometrics.

- *Connectionism, neural nets, and distributed processing models* in which stored information is distributed across the nodes of a net and learning rules describe how the connections among the nodes are modified with experience. The basic feature of such models is that the state of activation of each node is determined by the total influence from other elements across the connections and the strength of the connections is modified by experience. (The term neural nets arises because of a metaphor between nodes and neurons and connections and synapses).

- *Computational models* in which the processing can be thought of as algorithmic in character. Such models tend to be symbolic rather than analogical, and they tend to be conditional: If *y* occurs, do *x*.

Testing these models of information processing in individuals can be problematic for the reasons mentioned earlier: Experience tends to be irreversible and individual differences are ubiquitous. Thus, considerable ingenuity is required to get adequate data to tell how good a dynamic model is. In addition, there is considerable freedom in the details of the internal structures of such models, which until about a decade ago were entirely hypothetical. That may be changing rapidly with the development of passive methods of observing relatively gross brain activity and the use of single-unit recordings in animals to provide data about internal biological processes that are increasingly detailed and accurate at the neural level. It remains to be seen whether either of these two levels of physiological observation turns out to correspond to the level hypothesized in current information processing models.

Dynamic Processing Models of Social Behavior — Some of the difficulties of modeling individual behavior disappear when modeling social interactions, where it is possible to observe the structure directly. This is being done in a subfield of social psychology and sociology called social networks. Computers allow researchers to investigate large numbers of interacting elements, to seek structure within the network, and to track the behavior generated by the interactions over many trials. Although mathematical techniques continue to occupy a central role in modeling of psychological processes, computer simulation and visualization techniques increasingly are proving to be highly productive where traditional mathematical techniques seem insufficient.

A popular computer approach in social psychology is to model the emergence of global properties from interactions of individual elements. Two levels of social reality are typically investigated in this manner. In models of social cognition, elements correspond to components of the cognitive system, and the global level refers to such macroscopic properties of the system as decisions and judgments. At a higher level of social reality, elements correspond to individuals and the system-level properties refer to such group-level phenomena as cooperation (and lack thereof) in social dilemma situations, the formation of close relationships, and the emergence of public opinion.

Two of the most important general strategies of computer simulation have been connectionism, which was briefly discussed above, and cellular automata. The former is basically analogical and the latter discrete. Cellular automata are dynamic systems composed of many simple elements, each of which may display two or more discrete states, each one depending momentarily on the states of its neighbors. Although in principle such models could apply to individuals as well as social systems, most of the applications have been to the latter. The kinds of emergent patterns found include spatial patterns similar to social segregation and the emergence of coherent minority clusters from an initial random distribution of opinions. Equally important are the emergence of temporal patterns, including the evolution toward a stable equilibrium (fixed-point attractor), regular cycling through states (periodicity), and apparent randomness (chaos).

These complex emergent features of such models, which seem to resemble some social and behavioral phenomena, have attracted a great deal of attention. It has been known for decades that such emergent properties are possible. The hard problem remains: What are the detailed dynamics underlying a particular individual or social process? It is essential to remember that the mathematics or computations start with the dynamics and go to the emergent behavior, not the converse. Even if the converse were true, it would not help much because the empirical emergent behavior is known only very crudely. Here again we run afoul of the two facts mentioned at the onset: the irreversibility of most human behavior and the existence of major individual differences. These two facts make discovering the details of the dynamics of any such model very difficult. We know these are potentially attractive models, but selecting among them promises to be a very difficult, important, and long-term project.

Nonlinear Dynamic Behavioral Models — To a degree, this topic has already been broached, but what is surprising is that to get many of the emergent behaviors mentioned above, extremely simple dynamic systems suffice. Simple iteration of a nonlinear function can generate very complex patterns. The major requirement is that the system be non-linear, which means that the principle of superposition fails: Knowing how the system reacts separately to inputs *A* and *B* does not mean that simple summing describes how it reacts to *A* and *B* together.

The potential of this approach is enormous. Attempts are being made to use models of complex emerging behaviors in understanding movement and motor control, aspects of perception, attention, speech production, linguistics, and human development. This is especially productive in areas such as motor control, where it is feasible to collect sufficient data to test specific assumptions about the nature of the nonlinear dynamics. However, the usefulness of this modeling approach in other areas is contingent on uncovering the details of the dynamics involved.

Behavioral Genetics

Research in genetics cuts across all of psychology and serves as a two-way bridge between the behavioral and biological sciences. It is now generally accepted that genetic factors contribute importantly to most areas of psychology. Although research on the genetics of behavior has been conducted for many decades, the field-defining text was published in 1960. Since then, discoveries in behavioral genetics have grown at a rate matched in few other areas in the behavioral sciences.

Recognition of the importance of genetics is one of the most dramatic changes in the behavioral sciences during the past two decades. Until the 1970s, mental illnesses such as schizophrenia and autism were thought to be environmental in origin, with theories putting the blame on poor parenting. However, genetic research has convincingly demonstrated that genetic factors contribute importantly to most mental illness. In the case of schizophrenia, if one identical twin is schizophrenic, the chances are 45% that the other twin is also afflicted. For fraternal twins, the risk is 15%. It has recently been discovered that autism is one of the most heritable disorders, with 60% risk for identical twins and 10% for fraternal twins. The race is now on to find specific genes responsible for genetic influence in mental illness.

Genetics is not only important for disorders such as mental illness and cognitive disabilities; it also plays an important role in normal variation. No one is surprised to learn that normal variation in height is due largely to genetic differences among people. You might be more surprised to learn that differences in weight are almost as heritable as differences in height. Even though we can control how much we eat and are free to go on crash diets, differences among us in weight are much more a matter of nature (genetics) than nurture (environment). What about behavior? Genetics has been found to be important for normal variation in cognitive abilities, personality, school achievement, self-esteem, and drug use. Genetic factors are often as important as all other factors put together.

Genetic research is beginning to go beyond the rudimentary questions of whether and how much genes influence behavior, to ask questions about how genes influence behavior. For example, does genetic influence change during development? If you consider cognitive ability, for example, you might think that as time goes by, environmental differences might become increasingly important during the life span, whereas genetic differences become less important. However, genetic research shows just the opposite: Genetic influence on cognitive ability increases throughout the life span, from childhood to old age. This is an example of developmental genetic analysis.

Genetic research is also changing the way we think about the environment. For example, we used to think that growing up in the same family makes brothers and sisters similar psychologically. However, for most behavioral dimensions and disorders, it is genetics that accounts for similarity among siblings. Although the environment is important, environmental influences make siblings growing up in the same family different, not similar. This genetic research has sparked an explosion of environmental research looking for the environmental reasons why siblings in the same family are so different.

Recent genetic research has also shown a surprising result that emphasizes the need to take genetics into account when studying the environment: Many environmental measures used in the behavioral sciences show genetic influence. For example, research in developmental psychology often involves measures of parenting that are assumed to be measures of the family environment. However, research during the past decade has convincingly shown genetic influence on parenting measures. Genetic involvement has also been found for many other ostensible measures of the environment, including childhood accidents, life events, and social support. To some extent, people create their own experiences for genetic reasons.

The most exciting cross-cutting potential for genetic research on behavior involves harnessing the power of molecular genetics to identify specific genes responsible for ubiquitous genetic influence on behavior. This is part of a revolution in molecular genetics—a shift from studying simple single-gene qualitative disorders, such as Huntington's disease and thousands of other rare single-gene disorders, to studying multiple-gene influences, called quantitative trait loci, or QTLs, on complex quantitative dimensions epitomized by behavioral traits. QTLs merge the two worlds of genetic research—quantitative genetics and molecular genetics.

Although attention at the moment is focused on finding genes for complex behaviors, the question will soon become: What do we do with genes once they are identified? Molecular geneticists will try to characterize the genes at a cellular level. Behavioral scientists can use genes in less reductionistic levels of analysis that are likely to pay off more quickly in increased understanding of how genes affect behavior. It is difficult and expensive to identify genes but it is relatively easy and inexpensive to use genes once they are identified. For this reason, given appropriate training, psychologists will be able to use identified genes as another variable in their research. For example, they could chart the developmental course of the effects of genes on behavior, take a theory-driven approach to understanding the physiological and psychological mechanisms by which genes influence behavior, and address genetic links between normal variation and abnormal disorders. Especially important is the increased power specific genes will provide to investigate the interplay between genes and environment, including gene-environment interaction (are individuals who are at genetic risk more sensitive to psychosocial risk?), and gene-environment correlation (are individuals who are at genetic risk more likely to be exposed to psychosocial risk?).

NEUROIMAGING

The merging of theoretical investigations and experimental methodologies from basic psychological research with such technologies as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) is allowing novel ways of addressing fundamental psychological questions across a number of areas within basic psychology. Advances in neuroimaging techniques, which reveal brain structure and function, have enabled investigators to link thought, perception, and behavior to specific areas and pathways in the brain. Cognitive neuroscience integrates information from several related disciplines in order to develop hypotheses and models that explain the relationship between the brain and behavior. This area has exploded during the past few years as neuroimaging has been increasingly applied to the understanding of attention, language, memory, and emotion.

One advantage of neuroimaging is that it allows the development of models that incorporate the time dimension of brain-based cognitive behaviors, such as mental imagery, memory, language processes, and attention, as well as the division of labor and the sequence of activity among the different parts of the brain. Another advantage is that neuroimaging allows investigators to test hypotheses and conceptual frameworks that have been developed through observational laboratory research. For example, behavioral studies have indicated that people with schizophrenia exhibit cognitive dysmetria—a lack of coordination between various cognitive processes such as perception of time and self-awareness. This finding has been given strong support from PET scans that show abnormalities in the brain circuits involved in a broad range of cognitive tasks.

Neuroimaging is increasingly important in several areas of basic psychology. Many advances in understanding that have resulted from this approach have been described in this report. In addition, there are many other examples of advances in psychological research using imaging: Such research has helped demonstrate that the amygdala, a little cluster of cells on both sides of the brain, plays a crucial role in forming emotional memories. Recent studies have also shown how the visual cortex is involved in mental imagery. Still other studies have revealed that it is the left hemisphere that is primarily involved in syllogistic reasoning even when the problems are spatial in nature.

The development of modern brain-imaging techniques has been instrumental in the rapid development and maturation of cognitive neuroscience. However, because this area is so new, and because of the enormous significance of imaging techniques for research in the cognitive and behavioral neurosciences, deliberate efforts must be made to remove the barriers between disciplines that may serve to limit progress in this area. For example, imaging technology allows laboratory testing of the quantity and location of information that is stored in memory. But naturalistic studies address the content of memory — things like autobiographical information and eyewitness information — and how it is organized and retrieved. Both kinds of investigations are required in order to develop a complete picture of memory. Collaborations must be encouraged between investigators from disparate backgrounds who are looking at the same phenomena so that they can develop a unified theoretical vocabulary to explain both observable behavior and its neurophysiological basis.

Removing barriers between the disciplines involved in cognitive neuroscience also involves training. Psychological researchers need to be trained in the use of imaging in order to take advantage of these important technologies. By the same token, it is essential to ensure that researchers using imaging are familiar with the most current findings in behavioral science. Too often, when sophisticated imaging technology is used by nonpsychologists to demonstrate theoretical perspectives on cognitive behaviors, what they say is being learned or memorized or acted on in the brain is based on outmoded theories from psychology research prior to the 1970s. In such instances, the technology is spectacular packaging, but it doesn't advance our understanding of the processes of thinking, memory, and learning.

Modern cognitive psychology has advanced our knowledge about these functions at a level of sophistication that parallels the progress in brain-imaging research. We understand a great deal about how thoughts go together, how people read, and what is involved in different kinds of memory. There is a need for a new model of cross-disciplinary research training, one that emphasizes a balanced approach to the study of basic psychological phenomena by integrating the latest advances in neuroimaging techniques and cognitive theory. This model could be replicated in genetics, in virology, and in biology.

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