COGNITIVE PSYCHOLOGY AND INFORMATION PROCESSING: An Introduction

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COGNITIVE PSYCHOLOGY AND INFORMATION PROCESSING:
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Preface

PREMISE

Basic research, at its essence, is exploration of the unknown. When it is successful, isolated pieces of reality are deciphered and described. Most of the history of an empirical discipline consists of probes into this darkness—some bold, others careful and systematic. Most of these efforts are initially incorrect. At best, they are distant approximations to a reality that may not be correctly specified for centuries. How, then, can we describe the fragmented knowledge that characterizes a scientific discipline for most of its history?

The knowledge that a field claims at any point in its development cannot be unified, at that time, by a correct account of the phenomenon it studies; for that only becomes available much later. Throughout most of the history of a research science, reality does not unify its literature. What, then, does? It is our premise that the data, experiments, and theory of a developing field can only be fully understood by reference to the paradigmatic commitments of its practitioners. A dynamic field of science is held together by its paradigm.

Thomas Kuhn developed the concept of a scientific paradigm as part of a fundamental reformulation of views on the scientific enterprise. The paradigm, representing tacit commitments to a conception of reality that cannot be defended on rational or canonical grounds, stood in contrast to then-prevailing views of how science is done. Kuhn challenged the idea that scientific investigation is absolutely rational, thoroughly cumulative, and unequivocally objective. He highlighted the role of consensual judgments in determining what appears rational, objective, and worth cumulating. His most vociferous critics, philosophers of science by profession, have by now
largely conceded his major points. Although some have relabeled the concepts and denied their source, the astute reader cannot fail to discern Kuhn's thesis lurking in such alternative formulations as research programs, scientific disciplines, and scientific domains.

As psychologists, we may ask whether these diverting echoes from philosophy of science have much to do with us. Does psychology have a paradigm? We suggest that, in fact, it has several; and a grasp of this reality and its significance is essential to an understanding of psychological research at either the graduate or undergraduate level. In the first chapter, we suggest a way to define and analyze psychological paradigms. The psychological research literature speaks effectively to the existence of something like paradigms in our discipline. In 1970, for example, Mostofsky edited a book on attention, containing 18 articles. One of these was authored by Donald Broadbent. It was entitled "Stimulus Set and Response Set: Two Kinds of Selective Attention," and it contained 34 citations. In the same book appeared another paper by Werner Honig, entitled "Attention and the Modulation of Stimulus Control," and it carried 38 citations. Of the 72 articles cited by Broadbent and Honig, not one appeared in both citation lists. Obviously, if two psychological researchers could write about attention without citing a single common paper, there must be two distinct psychological literatures on the subject. This is anomalous for a cumulative enterprise, but comprehensible in paradigmatic terms. Our example from the study of attention is not unique. Anyone who has considered the treatments of early childhood autism in the Journal of Applied Behavioral Analysis and childhood schizophrenia in the Psychoanalytic Review must conclude that the psychologists differ more than the children about whom they write.

How can a student approach this kind of discontinuity in the literature? One approach, sometimes tried by undergraduates, is to suppose that the apparently different views can be reconciled. This leads to tortured logic and bizarre reference lists in term papers, as well as unrelenting frustration for their writers and graders. One can only speculate on what these students think we are doing by the time they have completed the B.A. Another approach is more typical of graduate training. It involves mastering one of the literatures and rejecting several others. Unfortunately, the student may often be encouraged to believe that the chosen approach represents the only correct and defensible—even the only scientific—way to study the topic at hand. This is the purchase of coherence at a high price.

We do not claim, or even know, that a student can effectively bridge several paradigms in the course of graduate training; and mastery of one is essential to the practice of scientific research. What we do claim is that, if a scientist is to remain viable, he or she must be prepared in the course of a 40-year professional career to reject at least one paradigm in favor of another. This cannot be accomplished by one who equates the consensual judgments of his...
or her reference group with the rational methods of science. A paradigm change in mid-career is less dislocating for one whose graduate education has placed those consensual paradigmatic judgments in the broader epistemological context—in short, for one whose graduate training has included explicit accounts of paradigmatic commitments.

For the undergraduate student, the literature of a developing science often seems fractured and chaotic. Apparently important issues go completely unresearched; seemingly trivial issues fill chapters. Negative evidence is given heavy weight in one case and lightly dismissed elsewhere. These patterns are understandable if, and only if, one understands the pretheoretical commitments of the practitioners of the science—in short, their paradigm. Undergraduate readers have found this treatment of the literature highly congenial and comprehensible.

We think it is essential to adequate scientific education to teach paradigms, and we believe that there is an effective method. The method emphasizes the integral nature, rather than the objective correctness, of a given set of consensual commitments. Moreover, we believe that paradigmatic content can be effectively combined with the technical research literature commonly presented in scientific texts. This book represents the culmination of those beliefs. You, the reader, will make the final judgment of their validity.

CONTRIBUTIONS

A major problem we faced as authors is that the field of cognitive psychology has become exceedingly large. No one, today, can seriously claim expert knowledge of the entire range of cognitive literature. Indeed, it is increasingly difficult to keep up with the data accumulating in a subfield such as memory or perception. The field of cognitive psychology seems to have exploded in the middle 1960s and has not touched ground since.

Our strategy in dealing with this situation was twofold. To organize and interrelate the rather disjunctive literatures in the various subfields of cognition, we adopted the notion of consensual validation and an elaboration of the Kuhnian concept of a scientific paradigm. The idea and its development are the contribution of Roy Lachman, who conceived this book at a time when the field was much smaller than it is today. Second, we attempted to set up a division of labor so that significant aspects of the cognitive literature could be covered in a nonsuperficial way. We started with Roy Lachman, Janet L. Lachman, and D. James Dooling. As each of us completed a first draft, the other two criticized it for later revision. We soon added Earl Butterfield; his job was to evaluate the first drafts and their critiques, to resolve any inconsistencies between them, and, most important, to rewrite all material in a language that would be readable by nonspecialists. The objective
was to ensure that the book did not assume professional expertise by our student readers, and to give the writing a coherence not always present in multi-authored texts. There were eventually some departures from this scheme, especially as the magnitude of the task became apparent. The final division of labor is represented in the following table:

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The production of the book was especially facilitated by our graduate student Carroll Thronesbery, who worked with us on the innumerable last-minute details. We also could not have dispensed with those who helped with the typing and bibliography. Especial thanks for her competent and loyal assistance in typing go to our secretary Fern Tombaugh.

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ABSTRACT

I. Introduction
Technical competence in a science is possible without perspective, and perspective is possible without technical skill.

A. Perspective and Content are Both Important to Science Education.
B. Beginning Definitions of Cognitive Psychology and Information Processing
A scientific field can be defined by its content, general approach, and specific approach. The content of cognitive psychology is the human higher mental processes, and the general method is the same as other sciences. The specific approach covered in this book is the information-processing paradigm.

C. Some Preliminary Examples of Cognitive Behavior
Automobile driving is the kind of activity that cognitive psychologists believe involves many important cognitive capabilities. We use this activity to introduce some of the emphases and assumptions of information-processing psychology.

D. The Significance of Information Processing and Cognitive Psychology
Paradigmatic views often find their way into the larger society, and we think the information-processing approach will have such an impact. Presently, it is most visible in cognitive science; but it is being extended. We advocate learning it along with other approaches.

II. Cognitive Psychology as an Experimental Science
A. Psychology Is a Research Science, Not a Mature System
This means that many psychological questions have not been clearly asked, let alone answered. The student should not approach an active research science seeking only established facts and agreed-upon theories. Learning about an unsettled research science involves learning the current questions, approaches, and controversies. These have their source in aspects of scientific practice that are often ignored in traditional descriptions of scientific method.
1. SCIENCE AND PARADIGMS: THE PREMISES OF THIS BOOK

B. A Fundamental Premise: The Rational and Conventional Rules of Science

Every scientist operates within two sets of rules. One is the rational rule system of the scientific method, which has been widely described. The other is conventional and paradigmatic; it results from consensus among a group of scientists that a particular approach is worthy.

1. The Rational Rules

While other human institutions make statements about mankind, scientific statements are unique. The rational rules of science are designed to obtain knowledge for its own sake: They are morally neutral and constructed to verify theoretical statements by observational methods.

2. The Conventional Rules

The rational rules supply more guidance in how to make observations than in what to observe. Intelligent, well-trained, and honest scientists can disagree about what to observe and what a particular observation means. Groups of scientists tend to form, however, within which there is considerable consensus on what observations are worth making and how they should be interpreted. The tacit rules followed by these subgroups constitute the conventional component of their science, their paradigm.

C. Normal and Revolutionary Science

Thomas Kuhn (1962) suggested that advanced sciences cycle between “normal” and “revolutionary” science. During periods of normal science, there is a sense of progress within the context of a particular paradigm, and little questioning of its premises. However, as experiments are done, anomalies arise that cannot be handled within the existing paradigm. When there is sufficient weight of these anomalies, the discipline may go into crisis and alter some of its most fundamental paradigmatic commitments. Although Kuhn’s contribution has been criticized, we think it is an excellent descriptive account of scientific activity and, with some modification, is highly appropriate to psychology.

D. Paradigms in Psychology

Psychology has always been, and still is, multiparadigmatic. However, at one time the dominant view was behavioristic. This has changed, partly due to the arrival of the information-processing approach. In cognitive psychology, the information-processing view was once revolutionary. It is now the dominant paradigm in cognition, and cognitive psychology now appears to be in a state of normal science.

III. Characteristics of Paradigms

Paradigms are not the same as theories. We suggest six dimensions along which paradigms may be defined and differentiated.

A. Intellectual Antecedents

These are the prior sources of the ideas and concepts that a scientist brings to his work.

B. Pretheoretical Ideas

The working scientist draws on assumptions and tacit beliefs about the nature of the reality he is studying. These guide research and aid in the formulation of experimental questions.

C. Subject Matter

The decision to study one facet of behavior and not another amounts to a judgment about which questions should be answered and which deferred.

D. Analogies

When a scientist is studying a poorly understood system, it is useful to borrow concepts and ideas from better-understood systems. This borrowing is tantamount to analogizing the two systems and can be used to develop theories and formulate research questions.
E. Concepts and Language The terms in a paradigmatic language can be imported from the paradigm's intellectual antecedents, or from a discipline which is the source of an important analogy, or invented within the paradigm. The language used within a paradigm reflects the pretheoretical ideas of its users.

F. Research Methods Whereas the rational rules dictate observational methods, paradigms tend to develop preferences for particular kinds of observations, experimental designs, and variables.

IV. Paradigms, Information Processing, Psychology, and Society

It usually takes a long time for a paradigm to have an impact on the wider society outside the discipline in which it is used. We think that the information-processing view of human capacities will eventually permeate institutions outside cognitive psychology. Therefore, we have taken considerable trouble to present as explicitly as possible the pretheoretical ideas, intellectual antecedents, subject matter, concepts and language, analogies, and research methods of the information-processing paradigm.

_The Lesson of the Copernican Revolution._ In the Ptolemaic system, as in the cosmogony of the Bible, man was assigned a central position in the universe, from which position he was ousted by Copernicus. Ever since, writers eager to drive the lesson home have urged us, resolutely and repeatedly, to abandon all sentimental egoism, and to see ourselves objectively in the true perspective of time and space. What precisely does this mean? In a full "main feature" film, recapitulating faithfully the complete history of the universe, the rise of human beings from the first beginnings of man to the achievements of the twentieth century would flash by in a single second. Alternatively, if we decided to examine the universe objectively in the sense of paying equal attention to portions of equal mass, this would result in a lifelong preoccupation with interstellar dust, relieved only at brief intervals by a survey of incandescent masses of hydrogen—not in a thousand million lifetimes would the turn come to give man even a second's notice. It goes without saying that no one—scientists included—looks at the universe this way, whatever lip-service is given to "objectivity". Nor should this surprise us. For, as human beings, we must inevitably see the universe from a centre lying within ourselves and speak about it in terms of a human language shaped by the exigencies of human intercourse. Any attempt rigorously to eliminate our human perspective from our picture of the world must lead to absurdity.

—from the opening paragraph of _Personal Knowledge_ (Polanyi, 1962)
I. INTRODUCTION

Science is an organized human activity having much in common with other human institutions. People can function effectively in a complex institution without necessarily understanding its history, social purpose, or properties. A businessman may know little of his nation's economy, yet earn great wealth. A general may not understand the causes of war, yet still win battles. A lawyer may know nothing of the history and social function of law, yet still win court cases. Beginning students sometimes do excellent technical work without necessarily knowing its importance. Scientists are human beings working within human institutions, just as are businesspeople, generals, and lawyers. Some of them can and do produce competent research without knowing its value, nor its place in the mosaic of knowledge, nor even the forces that directed them to the problems solved by their own findings. The point is that technical competence is not the same as perspective, in science or other human institutions. It is possible to have one without the other. The objective of this book is to provide both: a knowledge of the content of cognitive psychology, along with a perspective on that content.

Just as technical competence is possible without perspective, so perspective is possible without technical skill. People can grasp unifying views without practicing a specialty. They can understand war without fighting. They can understand law without trying cases. They can understand the economy without investing a dollar. Similarly, a student can gain a broad perspective on the sciences, or on a particular science, without earning a Ph.D. and setting to work in a laboratory.

A. Perspective and Content Are Both Important to Science Education

A few students intend to earn a Ph.D. in cognitive psychology and earn their living working in a laboratory; but the vast majority have no such intention. In this book, we hope to present the science of cognitive psychology so it can be grasped equally well by students who aspire to scientific specialization and those who do not. This requires that theories and data be analyzed relative to their place in the overall pattern of knowledge. Presenting technical facts, laws, and scientific theories is not enough, even though that is sometimes all one finds in science books and courses. We believe it is essential to bring broad perspectives to the teaching of science. Science and the student would benefit if more effort were spent on the pattern of knowledge to which theories and the data relate.

Science would benefit in two ways. Scientific research would be of better quality if all researchers understood where their work fit in the scheme of
things, and the importance of science would be more widely understood and appreciated among the general public. Students would benefit by gaining greater enjoyment and understanding from a scientific education that imparted perspective. They would be excited by discovering adjoining pieces of the puzzle of knowledge, rather than bored by memorizing lists of experiments whose relations to one another sometimes seem obscure. Becoming educated should be intellectually exciting. It is science's big ideas and sense of discovery, not just its technical details, that carry its excitement. This is fortunate, because it is impossible in the 4 years of a diversified undergraduate education to master the details of even one scientific subdiscipline. On the other hand, it is quite possible to achieve a broad appreciation of a science on the way to a baccalaureate degree. But here is a dilemma: Most science courses are taught by specialists. A few of them may lack perspective on their own fields; for others, perspective has become so nearly second nature that they forget to teach it. Textbooks are also written by specialists. Only a rare textbook integrates a technical literature so that it is understandable and interesting to the general student and the aspiring scientist alike.

Our goal in this book is to present an overview and perspective that will bring coherence and significance to cognitive psychology and to the information-processing approach to cognition. In the process, we present many experiments and their results. As we describe these experiments, we explicitly address why they were done and how they reflect the basic commitments of the scientists who did them. Of course, we also cover what they seem to show about human beings—their properties and their nature. Together, the intellectual motivation for research and the interpretations of experiments render cognitive psychology coherent and exciting.

B. Beginning Definitions of Cognitive Psychology and Information Processing

Cognitive psychology is one branch of an extremely broad field. Many content areas fall within the field of psychology, such as brain physiology, social interaction, and intrapsychic dynamics. The topic area of cognition, then, is one way to distinguish cognitive psychology from other branches of the general discipline. Psychology also includes many different methods of study; there are literary psychologists, intuitive psychologists, humanistic psychologists, and scientific psychologists, among others. Different methods can be used to study what is apparently the same subject matter. For instance, social interaction is studied both by scientific psychologists in the experimental laboratory and by humanistic psychologists in the encounter group. In order to mark out an area of study such as "cognitive psychology," then, we must specify both the content and the general approach.
The subject matter of cognitive psychology could be broadly defined as "how the mind works," but as such it would be completely intractable. The cognitive psychologist, like any other student of nature, must limit the subject matter to keep it comprehensible and manageable. Therefore, those aspects that seem especially important to most cognitive psychologists are studied—the "higher mental processes," including memory, perception, learning, thinking, reasoning, language, and understanding. Most students of the higher mental processes, moreover, have made a commitment to the observational methods of science rather than to a literary, intuitive, or humanistic point of view. The typical cognitive psychologist is, therefore, a scientist motivated to understand a natural system consisting of the human higher mental processes.

The commitment to use the scientific method in studying the higher mental processes obviously sets limits on one's scholarly investigations. However, a multitude of further decisions must be made, implicitly or explicitly, before the first experiment is begun. What assumptions are reasonable? What ideas are relevant in creating hypotheses about the nature of mental processes? What hypotheses are plausible and worthy of study? What should be studied first, and what should be deferred until later? Scientific psychologists can legitimately differ in the way they resolve these questions. However, within scientific disciplines, there tend to form subgroups whose members adopt very similar resolutions. When a sufficiently large number of scientists in a field agree to a considerable extent on how such questions are to be resolved, they are said to share a paradigm. Information-processing psychology is one paradigm for studying cognitive psychology, and it happens that in recent years it has become the dominant paradigm in the study of adult cognitive processes.

As we shall use the term, paradigm refers to the common set of ideas a subgroup of scientists brings to their subject matter. We develop the concept of paradigm in considerable detail in the rest of this chapter, for it is a pivotal concept in our treatment of the literature on cognition. Although the same term has been used to refer to particular laboratory techniques, our usage is quite different. It is also different from "theory," but these differences are explored later.

Because of the enormous complexity of most natural and social systems, no scientist can study the totality of a major system. Research can begin only after manageable-sized subsystems have been defined. Significant research requires the knowledge, foresight, and luck to formulate the properties and states of a subsystem that corresponds reasonably well to the real world. The scientist's paradigm plays a central role in this very significant task. Cognitive psychologists within the information-processing paradigm have a particular way of deciding which subsystems comprise the higher mental processes,
some insights and intuitions about what they are like, and some commitments regarding how they should be studied. They have defined the area of study as the way man collects, stores, modifies, and interprets environmental information or information already stored internally. They are interested in knowing how he adds information to his permanent knowledge of the world, how he accesses it again, and how he uses his knowledge in every facet of human activity. Information-processing-oriented cognitive psychologists believe that such collection, storage, interpretation, understanding, and use of environmental or internal information is cognition. They believe understanding these processes is fundamental to understanding reading, speech production and comprehension, and creative thought. Indeed, many cognitive psychologists believe that this research will aid in understanding other human characteristics, such as emotion, personality, and social interaction. Some cognitive psychologists believe that the properties they study—speech, understanding, and thought—distinguish human beings from every other natural system on earth.

C. Some Preliminary Examples of Cognitive Behavior

So far, our discussion of information-processing psychology has been both brief and abstract. It is greatly extended in the next two chapters. Before that, however, it might be useful to concretize our brief description through a familiar activity, analyzed from the information-processing psychologist’s point of view.

Most readers of this book probably know how to drive an automobile. Driving is the kind of activity that information-processing psychologists consider representative of tasks requiring many important cognitive processes. Although you are probably unaware of most of them, you perform countless internal acts as you drive your car. This is one characteristic of information-processing approaches to cognition: Many of the cognitive processes that interest information-processing psychologists occur without conscious awareness on the part of the individual who is performing them.

Consider your typical drive to your college or university. As you drive, you make various turns, each one signalled by some familiar landmark. These landmarks are so well known that you probably are not aware of “seeing” them each time. However, the information-processing psychologist is convinced that you must perceive each familiar landmark anew each time. You must recognize it as the same landmark that you have seen and used on previous occasions. How do you do this? From the information-processing viewpoint, you must have represented the landmark’s appearance in your memory. When you see it again, you match up your current perception of the landmark to its stored representation; this is the process of recognition.
Recognition also makes available to you other stored information about the significance of the landmark. Thus, when you have recognized it you can know whether you should turn right or left, proceed straight ahead, get ready to turn, and so on. Information-processing psychology is fundamentally committed to the concept of representation: Everything you know is considered to be represented in your memory. How these representations are put to use is one of the central questions in many areas of cognitive psychology.

We have mentioned two kinds of information about the landmark: perceptual knowledge about its appearance and conceptual knowledge of its significance. Both kinds of information are presumably represented, and they are called into play whenever a driver correctly executes the actions necessary to get to his or her destination. Another question that intrigues information-processing psychologists is the manner in which different kinds of information are represented. The area of cognition is also characterized by an assumption that represented information is somehow coded for storage in the human nervous system. This means that external events are converted into an internal form according to some specifiable sets of rules. Perhaps there is a different code for perceptual and conceptual information; or perhaps there is a single code that can be reached on the basis of visual or conceptual stimuli. Many areas of cognitive psychology are concerned with the various forms in which content may be coded.

As you drive, you take in vast amounts of environmental data. You “see” dozens of other cars, many buildings and trees, signs and signals. Some of this material is almost immediately forgotten; for example, another driver who is behaving normally is unlikely to be remembered later. However, if a driver behaves erratically, you may subsequently recall his actions. Subjectively it seems as if you see only the erratic drivers. But the information-processing psychologist considers that you could not distinguish the erratic drivers from the others if you did not process information about them all. However, much of this processing activity did not result in memory for what was processed. This possibility indicates that there must be different ways of processing information—some that result in memory and some that do not. Cognitive psychologists are interested in what the different processing modes might be and how the human cognitive system sets one or another mode into operation.

As you drive you also make numerous decisions. Some are deliberate and conscious—for example, you decide to pass up a distant parking space in hopes of finding a better one. However, many are made without your attention or awareness. If your car has a stick shift, you decide repeatedly when to shift gears. You decide when to speed up and slow down, when to change lanes, when to pass and when to wait. When a green light changes to
yellow, you decide whether to stop or proceed—in incorporating into your decision an estimate of how long the yellow light will last, whether there are cars approaching from the other direction, whether someone is behind you, and the speed of your own vehicle and its distance from the intersection. Quite a bit of data goes into this decision making, although for the most part you can do it without thinking about it. What is more, the decision may depend in part on whether you are late for class, whether you have a new or an old car, or whether your insurance is paid up. Information-processing psychologists consider that much cognition depends on internal decision making. Some is conscious, some unconscious, and some is completely outside the control of the individual. Nevertheless, such decision making is an important part of the information-processing approach to cognitive psychology.

The conviction that cognitive processes occur over time, and that some take longer than others, is another feature of information-processing psychology. Many information-processing experiments are designed expressly to find out how long different activities take. Many conclusions are drawn from what the researcher discovers about how much time a cognitive operation consumes. Temporal measures are used to estimate how complex a particular task is or how many suboperations, such as decisions, recodings, and mental searches, may possibly be involved. Now that we have called attention to some of the things we do without thinking about them, you may be able to describe some of the internal activities involved in your own driving. In fact; rational and intuitive analyses are respectable tools in the information-processing paradigm. Scientists who work within this paradigm believe that they can gain important insights by informal analysis of cognitive activities. But information-processing psychologists know that they cannot rely on rational and intuitive tools alone, precisely because so many cognitive processes go on outside of people's awareness. To know how people's minds work, information-processing psychologists must also use experimental tools, and they do so extensively. Some of these techniques are elegant and yield unexpected insights into how people work. Herein lies part of the fun of studying the information-processing paradigm.

Like all paradigms, the information-processing approach to human cognition has an intellectual history, a set of research tools, and a language that sets it off from other paradigms. Without understanding these, it is impossible to understand the paradigm and, concomitantly, the experiments and theories the paradigm has stimulated. There is much more discussion of these matters in the next chapter and throughout the book. We have used the information-processing paradigm as our organizing theme. It has guided our choice of chapters and of what to include in them. We know that this is not the only approach to cognitive psychology, nor will it last forever. In fact, in our final chapter we briefly describe recent and potentially important changes in
the approach. We simply believe that the scientific data on the higher mental processes are currently organized more comprehensively by the information-processing paradigm than by any other view.

D. The Significance of Information Processing and Cognitive Psychology

For those who plan to obtain advanced degrees and become professional psychologists, the significance of cognitive psychology and the information-processing orientation lies in the fact that these are important parts of contemporary psychology. A professional education is incomplete without some mastery of them. But this book is also for psychology majors who plan to stop with a bachelor's degree and, indeed, for those who are not psychology majors. It is intended to give an appreciation and comprehension of mankind's finest faculties, his mental ones. In the process, it accounts for some of the most intriguing features of science: its paradigmatic conventions and its revolutions. The information-processing approach has been in the forefront of a scientific revolution; it has provided psychologists with a fundamentally new way of thinking about people. Past ways of characterizing the most central characteristics of humankind have been quite different. For example, Freudian psychology focused on the clash between rational and irrational forces in shaping the human personality. Conflict between the demands of civilized society and innate, instinctive forces, which occurred primarily during infancy and early childhood, was considered a fundamental determinant of later behaviors. More recently, psychologists have viewed the human being as a conditioned responder, waiting passively for stimuli to impinge on him before emitting the response he has been conditioned to make. Both these views have been invoked to explain emotional behavior and psychopathology. Information-processing psychology differs from both Freudian and conditioning psychology. Our paradigm focuses on normal and rational behavior, and views the human being as an active seeker and user of information.

No approach explains all behavior; certain approaches seem to work best for certain kinds of human activities. This will long be the case in a developing science such as psychology. At the moment, the information-processing view seems congenial mostly to scholars of intelligent human behavior—it seems to work best in accounting for people's ability to accomplish familiar, well-learned mental operations. For the time being, it has little to say about emotional behavior, mental illness, or individual differences. However, the number of scholars who share the information-processing view is increasing. Some have applied the paradigm to social psychology (Carroll & Payne, 1976; Hendrick, 1977), developmental psychology (Klahr & Wallace,
I. INTRODUCTION

1976), and neuropsychology (Pribram, in press). Attempts have also been made to apply it to clinical psychology (Mahoney, 1974).

Freudian and behavioristic conceptions of man have been adopted by large segments of society. We anticipate that the information-processing conception will also work its way into social institutions outside of science. Information-processing conceptions are being used increasingly wherever survival depends on rapid and accurate dealings with changing and complex environments—for example, space travel and undersea exploration. The approach is also useful and will become increasingly important in school teaching, rehabilitation of perceptual and intellectual abnormalities, and in the communications fields.

Virtually every human activity is guided by a model of human nature. An implicit model of what people are like is responsible for the actions of police officers, salespersons, doctors, military officers, parents—in fact, everyone who interacts with other people. The use of some conception of man is universal and inescapable—whether the conception is valid or not. Insofar as the approach conveyed by this book is a valid picture of human capabilities, propensities, and behavior, learning it should improve one's effectiveness in many kinds of interactions with others.

We believe that an important piece of the truth is contained in the information-processing approach. It does not explain everything that humans do, but some human skills are explained more adequately in information-processing terms than in any other way. We advocate that a student learn this approach, and others as well. We believe that a complete education warrants learning a variety of approaches, such as dynamic, humanistic, and operant psychology, as well as information processing. A person who has mastered and understood several paradigms is in an excellent position to accomplish two important ends. First, he or she will be able to see the strengths and weaknesses of each approach as it applies to the aspects of human behavior that the person finds most interesting. The strengths of the information-processing view are most apparent to one who has tried to understand human intellectual capacities from behavioristic, psychoanalytic, and other viewpoints. Second, the person will be better able to deal with differences of approach, thus increasing receptivity to newer and more powerful conceptions as they are developed. Even the comprehension of established views will be facilitated. Each psychology course that is offered from a new vantage can increase a sense of disorder and chaos for the student who expects all of the facts collected by psychologists to fit into a coherent view. But for the student who has considered the similarities and differences between psychological paradigms, each new approach will fit a pattern and be easier to understand. Just as someone who knows two languages finds it easier to learn a third, so the student who understands scientific revolutions
and how they evolve will not be dislocated each time he encounters another paradigm. Scientific perspective consists in large measure of understanding how paradigmatic conceptions change. Cognitive psychology provides an excellent opportunity to understand such change, because it has so recently undergone one.

II. COGNITIVE PSYCHOLOGY AS AN EXPERIMENTAL SCIENCE

A. Psychology Is a Research Science, Not a Mature System

When they hear the word “science,” many people think of mature systems, such as planetary mechanics, thermodynamics, electromagnetism, or optics. They do not recognize the differences between these relatively advanced systems (Hanson, 1958) and very active research sciences, such as molecular biology, microphysics, and most areas of psychology. Mature systems were once wide-open research sciences; many experiments were done to answer questions about their subject matters. But today, many questions have been answered. The natural systems associated with these fields are now well understood, although they are sometimes subject to reinterpretation. Today, experiments are rarely conducted on fundamental issues. In fields like psychology, however, scientists are actively engaged in the most fundamental kinds of research. The answers to most of their questions are not known. No field of contemporary psychology has achieved the status of a mature science. Psychology is dynamic, changing, and unsettled, and it ranks among the most exciting of research sciences. This is one reason that psychology courses often do not seem to hang together—changes are first taught in the area that originated them, and other areas may not reflect the change for some time.

Learning a dynamic research science is different from learning an advanced system. An immature research science has a multitude of unanswered questions, and the student will find that many of them have not even been clearly asked. There is often substantial disagreement between scientists over how to frame the questions and about what evidence would answer them. You will be frustrated indeed if you approach an active research science like psychology as if it were made up primarily of finished systems of established facts and agreed-upon theories. Learning psychology consists as much in learning the current questions, controversies, and research approaches as it does in learning established facts. There is no single theoretical scheme to organize the facts and questions of a dynamic research science, as there is for more established fields. Moreover, the questions, controversies, and approaches within an immature and dynamic research science have hardly
ever been selected by applying textbook rules of scientific procedure. The choice of research questions, the character of current controversies, and the kinds of research approaches in use are comprehensible and interesting only in view of their social-intellectual roots. Throughout this book, we have provided the relevant contemporary antecedents and recent history to help make cognitive psychology orderly.

The controversies between scientists in an active research field can be particularly disorganizing for students. The student's problem is to distinguish the controversies that are central to the field, or at its frontiers, from those that are peripheral. Methodological issues can and often do fascinate research scientists; there are occasional researchers who make whole careers pursuing them. George Miller, a leading cognitive psychologist, has argued that methodological issues are bread and butter to the working scientist but can be spinach to everyone else. We have tried to avoid this source of difficulty by not presenting issues whose resolution will have limited effects on cognitive psychology. We have not presented data about issues which we judge peripheral, even if there are numerous experiments on them in the technical literature of our field.

It is also true of a research science that seemingly well-established facts are sometimes called into question by single pieces of conflicting data or by novel interpretations of old results. The facts and theories of a research science are variously qualified, depending on which other facts and interpretations one acknowledges. When writing about research sciences, textbook writers often try to present all possible qualifications to every fact or interpretation they discuss. This thoroughness can ensure that they will not offend the scientists who have discovered the qualifications, but it can also obscure the major generalizations that a student strives to grasp. The main outlines and important features of a research science can sometimes be seen more easily by simply ignoring data that are endlessly qualified and requalified. In this book, we have omitted qualifications that seem to confuse rather than clarify fundamental issues. We have tried, in short, to strike a balance between oversimplification and overcomplication.

Science is a human institution, and as such it suffers from human frailties and shortcomings. It is important to distinguish the actual from the ideal conduct of science as a preliminary to understanding the activities within a particular scientific field, such as cognitive psychology. Much of the chaos that so often seems to characterize an active research discipline results from an incongruence between the way the discipline is said to be studied and the way it is actually carried out. One reason research sciences often seem incomprehensible to the beginner is that the published research report often does not correspond in a one-to-one fashion to the actual conduct of inquiry. Scientific research is sometimes portrayed as if it were a completely rational, progressive business that moves steadily forward. New questions are
supposedly generated only by gaps in knowledge or by unexplained facts. Experiments are presumably conducted only to test deductions from scientific theory. Theories are wisely discarded if the experiments give results that do not conform to the deductions from them; and the best theory is adopted, though only tentatively, of course. Few working scientists actually accept this as an accurate account of how science is done. A careful examination of the theoretical and experimental activities of scientists suggests that scientific inquiry is considerably more complicated and much more interesting than this false stereotype (Kessel, 1969).

This stereotyped view of science might be the only way to teach a high school course or the most elementary college course, but it causes great grief to the serious student. It provides no way of understanding why obviously important issues go completely unresearched, while experiments on some minor topics fill whole journals and books and then disappear. Why do so many experiments sometimes produce so little progress in theory? How can well-established theories be completely discarded and replaced by new ones? The stereotyped view leaves questions like these completely unanswered, and science ends up seeming incomprehensible. It is not. Questions like these can be answered. The answer begins here: There is more than one set of rules by which science is done.

B. A Fundamental Premise:

The Rational and Conventional Rules of Science

Every scientist has made a commitment to certain procedures that qualify his or her work as "science" rather than as something else. These rules are well known and publicized; they constitute the scientific method. The rational rules of science are quite similar from one discipline to another. They are shared by physicists, biologists, and social scientists. However, if you have ever tried to use your understanding of a physical science to understand psychological research, you have probably found that there were as many differences as commonalities. Understanding the rational rules is essential, but it is not enough to render the actual experiments and theories of a science obvious and comprehensible. The reason is that every scientist uses a second set of rules in addition to those of the scientific method. The second set of rules is conventional, in the sense that several or many scientists agree that they are appropriate. However, while every science has conventional rules, they are not the same from one scientific discipline to another. Even scholars within a single discipline may subscribe to different conventional rules. When a group of scientists share essentially the same conventional guidelines for formulating research questions and structuring experiments to answer them, they are members of the same scientific paradigm.
The fundamental premise of this book is that an active research science cannot be intelligently understood by reference to the rational rules of science alone. It is equally necessary to understanding the paradigm that guides the scientists who do the experiments. Without understanding the paradigm, a student may find the experiments unrelated to each other; or the answers the experiments are supposed to provide may seem incomprehensible. The questions the scientists have chosen to ask may seem trivial or exotic, and their controversies may resemble tempests in teapots. However, to the student who grasps the paradigm guiding the research, the relationship between theory and experiment will become clearer. The way in which experiments relate to each other will become more evident. The questions scholars in the field have chosen to ask will not seem so arbitrary, and their approach to answering the questions will look more reasonable. The field as a whole will have coherence and relevance to the student who understands the intellectual motives of the scientists who comprise it—include their rational rule system and their conventional, paradigmatic one.

1. The Rational Rules

Let us first consider the rational aspects of science, for it is these that distinguish science from other human institutions that make claims about human nature. Religion, art, poetry, political organizations, legal scholars, the military arts, encounter groups, and meditators are all sources of claims about people— their motives, essence, and actions. There are at least two fundamental differences between scientific methods for the study of mankind and nonscientific methods, such as religion and political ideology. The first concerns their objectives. Science may be unique, in that it is the only institution whose ultimate objective is obtaining knowledge for its own sake. The rational rules prescribe no prior commitment to what the truth is; the institution is designed to discover the truth and, when it is found, either to stop there or to transmit the findings to technology. Other institutions, such as religion and politico-legal systems, also make and defend claims about the way people actually are; but these claims are primarily in support of the institution’s role in defining correct and incorrect action. The truth claims are not an end unto themselves, but are offered as foundations for prescribing moral rights and wrongs. The formal institutional rules of scientific method include no way to translate scientific discovery into prescriptions of the right thing to do; in fact, they preclude it. Science’s rational component, for example, may be used to determine the number of deaths attributable to abortion or how to reduce this number, but it cannot render a judgment whether abortion is right or wrong. The rational rules can provide estimates of the incidence of premarital sex, but they cannot be invoked to judge the
moral appropriateness of sex before marriage. It is true that scientists sometimes go on record for or against some moral principle, and this is legitimate if they are speaking as persons with moral views. However, the community of scientists does not accord universal adulation to a colleague who represents his moral conclusions as scientific discovery, however much they themselves may agree with the conclusions.

The second major difference between the rational rules for scientific conclusions and alternative methods resides in the scientific ideal for verification. The rational component of science demands that scientific beliefs at some point be tested against observable evidence. Science, in principle, has no axioms that are sacred and invulnerable to observational test. As we shall see, there are paradigmatic assumptions that may in fact never be tested, and that serve as a starting point for theory construction; but ideally even these assumptions are candidates for abandonment in the face of contrary observational evidence. As we shall also see, there is considerable latitude in the way observations relate to theoretical claims; but in the rational rules of scientific procedure, observational data provide the final criterion for determining the truth or falsity of such claims. Other sources of knowledge claims do no institutionalize observational data to this extent. In religion, for example, new claims are considered in light of their consistency with the axioms of the faith. Claims that are derived from the axioms are considered true; claims that are inconsistent with the axioms or their derivatives are false. The axioms are permanent, given, and unquestionable; their source is divine revelation. For example, Milne (1952) wondered whether Christian theology was threatened by the existence of countless planets in the universe, any one of which might contain intelligent beings. He noted that the Christian would either have to deny the existence of life on other planets or accept the possibility that the Incarnation of Christ was repeated countless times throughout the universe. A theologian (Mascall, 1956) considered this possibility from a theological point of view, and argued that Milne had a poor understanding of the fundamental Christian position on the Incarnation. Nothing in that position precluded the possibility that man might be one of a family of intelligent beings redeemed by Christ, or that man might be the only species that had fallen and needed redemption, or several other possibilities. The point here is that Mascall considered the findings of cosmology as they related to the axioms of Christianity. His theological judgment rested on consistency with these axioms rather than on observational test. Acceptability of truth claims, thus, rests on a different basis in religion and in the formal rules of science.

The test of truth in political ideologies is also consistency with a set of axioms, although these axioms may have a different source from those of religion. They may consist of truths held to be self-evident, as in the American Declaration of Independence. Or they may be rooted in divine will, as is the
II. COGNITIVE PSYCHOLOGY AS AN EXPERIMENTAL SCIENCE

doctrine of the divine right of kings. They may rest on a particularly influential analysis of historical forces, as does Marxism. Whatever the source, however, the axioms that form the basis of political ideology are not open to question. New situations are analyzed in terms of the existing axioms and are not taken as potential evidence that the axioms are wrong. Political and religious institutions contain no mechanism for changing the axioms; such change is not part of the institution’s internal structure. This is one difference between such systems and science. Even well-established beliefs in science are in principle open to question, and their occasional abandonment is considered an acceptable part of the way science is supposed to function.

Thus, the rational rules of science differentiate scientific claims from those of other institutions that also make assertions about nature. Perhaps for this reason, scientists are somewhat self-conscious about how they prove their claims. Many, many textbooks describe the rational procedures for scientific verification of truth. All scientists know these rules well, and there is no question that they guide scientists in their daily work. But they are not the only guide scientists use. There are also the conventional parts of scientific decision making.

2. The Conventional Rules

It has been known for a long time that scientific inquiry takes much of its direction from certain intellectual commitments that scientists have not clearly stated (cf. Polanyi, 1962; Popper, 1959). Still, until recently, most textbook accounts of the rational component of science presented it as if it were an essentially complete account of how science is done. The problem is that the rules are prescriptive and define how science should be done. To understand an actual science, a student really needs descriptive information about how the science is actually done. Otherwise, the student’s position is analogous to trying to understand congressional action by reference to the U.S. Constitution and Robert’s Rules of Order. Certainly, these codified rules place constraints on what senators and representatives do. However, much of what occurs in congressional sessions must be explained by reference to particular personalities and the characteristics of their constituencies, special relationships between individual members of Congress, temporary alliances, and a host of other factors that could not be codified in the Constitution or parliamentary procedural rules. This does not mean just covert violations of the rules, such as influence peddling or bribery. Many deals are made off the floor, with members of Congress agreeing to vote for each other’s bills. This is a perfectly legitimate activity; it is not precluded by the Constitution, but neither is it explained by the Constitution. The length of filibusters, the function of party whips, and even the positions taken by members of opposite political parties can be understood only by reference to pragmatic factors...
outside the scope of the Constitution and Robert's Rules. It is not that these
documents are wrong; but in accounting for the activities and votes of real
senators and representatives, they are incomplete. So it is with the rational
rules of science.

The canonical (rule-governed) component of scientific method requires
that hypothetical accounts of natural-system properties be verified by
observation. Empirical corroboration in science is a complex and controver-
sial subject. However, even though it is an oversimplification, it is reasonable
to say that the rules provide some guidance in how to make observations that
will confirm or disconfirm proposed accounts of nature. There are prescribed
methods, for example, of structuring an experiment so as to isolate the causal
effects of a particular variable. However one views the current state of
development of canonical methodology, the rules are of little help in choosing
which variable to study. The rational component of science provides much
more guidance in how to observe than in selecting what to observe. In
selecting what to observe, a researcher must rely on other sources of ideas—
and the source that most researchers use is the "collective wisdom" of other
researchers in the field. Such collective wisdom results partly from previous
observation and experimentation; but it is also the product of "working
assumptions" that others have made and found useful in formulating
previous research. The working assumptions may never have been directly
validated by experiment. They may have been indirectly supported, in the
sense that productive experimentation has resulted from making them; and
many scientists in the field may be quite convinced of their validity. However,
the fundamental status of such working assumptions is different from
empirically validated fact. They are consensually validated by collective
judgment, not confirmed by direct experimental test.

Interpretations that are made of experimental data are also influenced by
"collective wisdom." The rational rules of science impose some constraints on
how a researcher may interpret his observations; for example, he cannot
ignore the requirements of logic. Nevertheless, logical requirements do not
completely determine a researcher's interpretations. The behavior of a rat in a
Skinner box has at various times been interpreted as verifying, or not
verifying, claims about how animals learn; and "animals" has been taken to
include people. But to invoke the data of rat experiments in theories of
complex human learning, one must assume that human and rat learning is
similar in essential respects. Is this assumption empirically justified? Are there
experiments in the psychological literature that have directly tested it? The
answer is no, although for many years the assumption was widely accepted
among experimental psychologists. Today, very few cognitive psychologists
are comfortable with the assumption that complex human learning can be
understood by extrapolation from the behavior of rats. Psychologists of
human learning once supported such an assumption by consensus; but now
their collective judgment has changed. Is this because experiments have proved the assumption wrong? The answer, again, is no. No one can point to a single experimental outcome that changed nearly everybody’s mind. The change resulted from informal judgments rather than the application of formal scientific methods. The judgments were made by intelligent and well-read people who know a great deal about the experimental data of psychology; but they were judgments nonetheless. If the assumption of essential comparability between human and rat learning had been directly rejected by experimental observation, every respectable behavioral scientist who knew his trade would by now have abandoned it. However, there are perfectly respectable scientific psychologists, whose sanity, honor, and intellect are not in question, who still feel that animal behavior can illustrate important aspects of complex human learning abilities. Among students of complex human learning they are a vanishing minority, but their very existence is evidence that the rules of scientific procedure leave considerable room for different strategic interpretations of data on the part of decent, intelligent scholars.

The central premise of this book is that the character of a science is shaped as much by paradigmatic judgments as by the canons of scientific method. Consequently, understanding the paradigm is as much a part of learning the field as studying the experiments themselves. Like all judgments, paradigmatic ones leave room for fundamental differences in approach. If the rational rules of science determined all aspects of scientific decision making, there would be no room for different approaches and no need to learn paradigms. When differences of opinion arose, we would simply do the necessary experiment, and everyone would draw the same conclusion from the outcome. This ideal state of affairs does not obtain and never will. Partisans of different paradigms do not agree on what the “necessary experiment” should look like. Typically, they do not usually communicate and therefore do not discuss the matter. If they did communicate, competent scholars would still disagree on what the outcome means if they did not share the same conventions for interpreting results. It is not the data about which they might disagree; it is the meaning of the data. While all competent observers might agree that an experimental rat turned left at a certain time under certain conditions, some may absolutely refuse to draw any conclusion about human activity from this fact. Does this mean that a set of consensually validated judgments is essential to make rationally derived scientific observations meaningful? We think precisely so.

Seeing that both conventional and rational systems guide what scientists do is particularly informative for psychology students. The key point is that one cannot completely make sense of a scientific literature containing only the rational component. One must also understand paradigmatic decision making in science. Psychology has had more than its share of paradigmatic
shake-ups in its short history, and these are best explained by reference to the tacit, conventional component of scientific psychology. The shake-ups are completely incomprehensible to the student who believes that a good scientist follows the data wherever they lead and that only incompetent or dishonest scientists let their preconceptions determine the experiments they do and how they do them. Actually, all scientists regularly let their preconceptions dictate what they will do next. They fall back on their conventional wisdom whenever the rational rules fail them, which is often. The scientist makes many decisions by reference to an inexplicit ideology acquired through years of professional training. This ideology—the researcher's scientific paradigm—should not be viewed as an irrational character flaw that detracts from the rationality of science. Rather, it is an essential supplement to the rational aspects of scientific procedure. The paradigm forms the context in which the rationally derived procedures of science can be meaningful and interpretable. Learning the paradigm of a scientific discipline is a large part of becoming an expert in the field. It is just as important to absorb the conventions for motivating experiments and interpreting experimental data as it is to become familiar with the facts. As our opening quote from Polanyi (1962) illustrates, the facts really do not "speak for themselves."

Thomas Kuhn (1962) was the first to introduce a systematic treatment of paradigms in science; and he did so in the context of a distinction he wished to make between "normal" and "revolutionary" science. The impact of paradigms on the practitioners of science is quite different in periods of normal and revolutionary science, but it is present in both.

C. Normal and Revolutionary Science

Since Thomas Kuhn published his book on comprehensive scientific paradigms in 1962, there have been several important reactions. Kuhn's book has become the most widely read interpretation of the nature of science. His original viewpoint has been the subject of a variety of criticisms in the literature on the philosophy of science. In response to his critics, Kuhn has changed various details of his position (1962, 1970a, 1970b, 1970c, 1974). Before publication of the original treatise, an "accumulation model" of scientific knowledge was the dominant conception. According to this view, progress in science consisted of the cumulative growth of factual discoveries, improvements in methods, and theoretical generalizations. Kuhn challenged this pervasive view. He argued that, in advanced and mature sciences, progress is not linear but alternating. He suggested that theoretical sciences cycle between a state he called normal science and a state of extraordinary or revolutionary science. Normal science consists of coherent traditions of day-to-day research activities. These activities are theoretical, methodological, and experimental; and they are justified and unified by the paradigm from
which they emerge. The paradigm includes the intellectual commitments and
gains of a community of like-minded scientists; it provides model problems
to the community and defines the domain of acceptable solutions. The
paradigm is not necessarily identified with a particular scientific theory, law,
or method. It is more global, taking in the full range of implicit and explicit
communal assumptions. Normal science is guided and structured by the
paradigm. It produces research that extends and elucidates those facts that
the paradigm suggests are most revealing. The paradigm sanctions methods
known to, and accepted by, the paradigmatic community. In the course of
normal science, the methods may also be extended, modified, and refined. As
normal science proceeds under the auspices of a given paradigm, Kuhn
describes two things that happen in advanced, mature disciplines such as
physics: A stable body of knowledge grows and develops, and a small number
of unsolved—perhaps insoluble—problems accumulate. The unsolved
problems are called anomalies. One kind of anomaly is the failure of well-
established theories, sanctioned by the paradigm, to predict experimental
outcomes. Another is the failure of experiments to replicate. Whenever
experimentation persistently fails to produce results consistent with the way
the science has integrated and interpreted broad areas of prevailing
knowledge, an anomaly exists. When enough anomalies arise, or when a
particularly striking anomaly is reported, the discipline may go into crisis and
change in character from normal to extraordinary science. If an alternative
paradigm is put forth that can resolve the anomalies and shortcomings of the
dominant one, a scientific revolution takes place. Scientific revolutions, in
Kuhn's view, are noncumulative episodes in which most practitioners reject a
dominant paradigm and accept, in whole or in part, the new commitments of
a new paradigm. The revolutionary change to a new paradigm may mean
significant changes in the scientists' conception of what problems are
important, what solutions are acceptable, and what theoretical language is
appropriate to those solutions. This is a truly revolutionary state of affairs,
much like an ideologically based political revolution. As a matter of fact, the
term “revolution” in politics came from science. It originated in the title of
Copernicus' book referring to the revolutions of heavenly bodies—a book
that provoked the archetype of all revolutions, intellectual or political.

Kuhn's book accelerated the rejection of views about science that had been
accepted for many generations. Not surprisingly, his thesis has been
vociferously attacked, mainly by philosophers of science (Lakatos, 1970;
Popper, 1970; Shapere, 1971; Scheffler, 1972). One major objection concerns
the concept of “paradigm,” and a second is Kuhn's alleged acceptance of
“irrationality.”

Kuhn uses the paradigm concept in two important ways. One usage is
essentially sociological, and refers to a community of scientists who function
rather like a culture or subculture. The other usage refers to the particular
commitments of the scientific culture: the scientific beliefs and values of the paradigmatic community and the particular puzzles, problems, and solutions those values support. Because a paradigm develops conventionally, without explicit documentation of its rules, some philosophers of science have rejected the "paradigm" concept as too vague and intuitive. But of course many useful concepts, such as "culture" and "common law," are likewise vague and intuitive and require development; nevertheless, they refer to a coherent reality. As a matter of fact, even critics who reject Kuhn's conception of the paradigm concept concede the distinction between normal and revolutionary science (e.g., Popper, 1970; Shapere, 1971). Because the rational rules do not change during revolutions, the distinction implies the existence of some other source of the overriding commitments that do change when scientific revolutions occur.

Other critics charge that Kuhn essentially defends irrationality (Suppe, 1977). This charge stems from the way Kuhn developed the concept of paradigms. His thesis implies that choice among paradigms cannot be made on reasoned objective grounds. One paradigm can never be objectively proven to be better than another. The problem is less with Kuhn, in this case, than with the philosophical conception of "rationality." The concept is somewhat underdeveloped, and for some philosophers encompasses only those judgments and conclusions that can be supported by existing formal or mathematical reasoning. Human reason, including that of scientists, no doubt includes components that have not yet been formally characterized. Kuhn's thesis is not that scientific judgments are made irrationally. We understand him to mean only that many such judgments involve a kind of reasoning that philosophers have not yet formalized.

Kuhn's conceptions on the growth of scientific knowledge have helped replace a long-prevailing view of science. That view, which grew out of the earlier tenets of logical positivism, fostered an unnaturally static view of the methodology of science. All competent students of science agree on the dynamic, everchanging character of the scientific enterprise: Methods, assumptions, facts, and theories are all continually modified, updated, reinterpreted, and sometimes abandoned. The process of change is surely one of the universal features of the scientific enterprise. Kuhn's formulations will likewise be altered, refined, and reinterpreted to give a richer and more accurate picture of modern science. Other philosophers of science are attempting to formulate their own accounts of the underlying systems of working assumptions used by scientists. These accounts are not identical with Kuhn's, of course, and their authors use different terms to avoid conceptual confusion. For example, Lakatos (1970) uses the term "problem shifts" rather than "revolution," and "research programs" instead of "paradigm." Toulmin (1972) characterizes scientific "disciplines" and their "evolution," and
II. COGNITIVE PSYCHOLOGY AS AN EXPERIMENTAL SCIENCE

Shapere (1977) describes scientific "domains" and how they are affected by "radical new hypotheses." The particulars of these alternatives differ from each other and from Kuhn's work. But all are attempting to deal with the reality that there are systems of assumption in science larger than formal theories, and to document how the assumptions change over time. Our treatment of the information-processing paradigm and its properties does not require a choice among the formulations that presently exist or are currently under development.

Kuhn's original analysis was developed for advanced, mature sciences, primarily the physical sciences. It requires some adaptation and modification as applied to psychology. We have taken the concepts of paradigm, normal science, anomaly, and revolution and have reconceptualized them to provide a novel account of cognitive psychology (cf. Segal & Lachman, 1972; Weimer & Palermo, 1973). Let us now take some of these rather abstract considerations and illustrate them by recent psychological events, in particular the decline of behaviorism. You have doubtless encountered aspects of behaviorism in one or more of your psychology courses, and we later describe in detail its impact on contemporary views of cognition. At one time, behaviorism was the dominant paradigm in American experimental psychology. It is no longer so. Let us consider this transition, which parallels the concept of a scientific revolution that Kuhn developed for mature sciences.

For many years, the majority of psychologists conducted normal scientific research into learning. Their research was based on certain important paradigmatic assumptions. They believed that most behavior was the result of learning and that relatively little could be attributed to innate abilities. They assumed that many species learned in the same way. They regarded learning as the formation of conditioned associations between external stimulus events and responses. These beliefs were not based on data, they were the conventional component of the scientific psychology of the time. The beliefs seemed plausible, and they helped psychologists decide what experiments were likely to be important and which observations would validly test their theories. For years, the study of learning proceeded as normal psychological science: Several theories of learning were formulated and tested with many experiments, which were usually performed on animals, such as the white rat.

Psychology entered a revolutionary period when many scientists began to question the conventional commitments of the learning theorists. The possibility of innate abilities was seriously reconsidered. Many psychologists came to believe that different species have different ways of learning. They raised the possibility that the formation of associations between stimuli and responses was not the only kind of learning. They even suggested that humans often learn in other ways. These changes in what psychologists believed were
sometimes based partly on data, and sometimes on no data at all; but many researchers found the new commitments more plausible and more useful as guides to important and successful experiments.

The new beliefs were a massive challenge to learning theorists, because they struck at the very reasons for their research. If there were important innate abilities, then the centrality of learning to human behavior had been overplayed, and the energy devoted to studying it had been altogether disproportionate. If different species have different learning mechanisms, then data and theory about how animals learn might say nothing important about humans. If learning was not primarily a matter of conditioning, then painstakingly constructed theories of how stimuli are associated with responses by conditioning would be a small and perhaps trivial part of the science of psychology, rather than its very core. Such changed conceptions were revolutionary; they challenged the foundations on which most psychological theories were built; they implied that learning theory explained little of central importance. According to the new conceptions, it made no difference whether a particular learning theory was right or wrong: They were all seen as irrelevant, and research done to test any of them was uninteresting. The data collected when learning theory dominated normal psychological science were either reinterpreted in light of newer paradigms or discarded as insignificant. Although these newer views are not universally accepted, they represent the judgment of a substantial number of cognitive psychologists.

Scientific progress is cumulative, but only during periods of normal science. During scientific revolutions the conventional part of a science is changed drastically, and some or all of the data and theory of the preceding normal-science paradigm may be thrown out, ignored, or reinterpreted. Why do new paradigms replace old ones in psychology? Because many psychologists find them more helpful in their daily decision making and in becoming a successful scientist. They help answer questions like these: What are the probable components of the system I am studying? What are the important scientific questions of today? What observations can I make to help answer those questions? What experiment should I do first? Which experiments should be done at all? What should I measure? What conclusions do my observations justify? Scientists must answer these questions, and they regularly do, without reference to the rational rules. They answer such questions by referring to their conventional, paradigmatic beliefs.

The concepts and idea systems that make up a scientist's paradigm are usually learned while he is a student. They are learned primarily in graduate school, where the beginning scientist picks up the tricks of his trade. Some examples of conventionally accepted psychological concepts are the stimulus–response association, secondary reinforcement, uncertainty, representation, and propositional meaning. You may not have encountered the last two in previous courses, but they occur frequently in this book. Individual
researchers may differ in how they use such concepts; but during periods of normal science, certain concepts are familiar to many scientists and their status is seldom questioned.

If scientists acquire their paradigms as students, what maintains their conventional beliefs later? The opinions of their peers, largely. Research is not a private matter performed alone in a laboratory. Psychologists, like all scientists, must regularly interact with one another. Although the public character of science is universally acknowledged, the extent to which the opinion of colleagues dictates a scientist's career and determines success is less widely appreciated. Whether or not a researcher publishes his experimental findings depends on other scientists; they read the reports and decide whether the work merits publication. When promotion is due, other scientists evaluate their colleague's scholarship and decide whether he or she will advance academically. When the scientist seeks money to support ongoing work, his or her research proposals are rated by colleagues; and unless they approve, the researcher receives no funds. Other scientists decide whether one's students should be graduated. When those students seek jobs, other scientists decide whether to hire them. Scientists have a deep personal investment in publishing their findings, in being promoted, in having the money to conduct their research, in having their students pass their doctoral examinations and find good jobs. These are some of the reasons it is to the scientist's advantage to gain and keep the high regard of fellow colleagues. This is far easier if one conducts one's research and trains one's students in a generally accepted paradigm.

Revolutionary science is extremely hard on established researchers, and this, too, contributes to the maintenance of normal science. Paradigmatic shifts beckon the established scientist to change his conception of reality and his view of his field. If he is to keep up, he must abandon familiar, well-understood concepts and ways of thinking; he must become something of a student again. He must retrain himself in a paradigm in which others are more expert. He may have to learn new research techniques. He may even have to abandon costly laboratory equipment that was suited to the old paradigm's research, and buy new equipment suited to the methods of the new paradigm. A scientist who is eminent in the practice of an established paradigm may become an obscure practitioner of an ascending one.

All this may suggest that scientists are bludgeoned into submission. On the contrary, most operate very comfortably within their scientific paradigm. Scientists have usually been trained in their paradigm, and they have a comforting sense of its correctness. It frees them from pondering extremely complex questions, such as "Where is my field going and how can I contribute to changing it?" It allows them to get on with their work. The community of scientists who share a paradigm function much like a family: They support one another; they provide validation for one another's work; they understand
in a way that others do not. And the paradigm provides convenient ways to
discount the work of incompetents and maniacs. Remember, scientists are
human too.

How, then, does a paradigm ever die or decline? What brings on a scientific
revolution? Why doesn't normal psychological science run forever? Para-
digms fall slowly, from the weight of repeated failure. Problems that all agree
need to be solved go untouched by research within the paradigm. Or, a
particular kind of experiment may consistently fail to come out according to
paradigmatic expectations. The unexpected results may be impossible to
interpret within the paradigm unless the scientist makes absurd assumptions.
Such occurrences can produce great dissatisfaction with a prevailing
paradigm. Frustration can also result from the failure of experimental results
to hold across similar settings. Experimental changes that are trivial
according to the paradigm may completely reverse the outcome of an
experiment. There is nothing quite so frustrating in the everyday life of a
research psychologist as losing his usual findings by virtue of seemingly
insignificant procedural variations. Another contributor to the fall of a
paradigm is a sense that theory is not
developing. Facts about the same
behavioral system seem to remain unrelated for long periods of time. Even
though there are many social pressures to continue normal science as usual,
circumstances like these lead scientists to seek new ways of viewing their field.
For example, one factor leading to the information-processing revolution
was the lack of progress in understanding how people learn to read. There was
enormous dissatisfaction with progress—in fact, there was none. A book
written in 1908 remained, in 1968, the best available work on human reading,
and was reprinted that year (Huey, 1908/1968). For a psychology that had for
years been deeply committed to understanding learning, this was intolerable.
The importance of reading could not be denied, but research based on
learning theory ran into repeated dead ends. Ultimately, psychologists sought
new approaches, and the information-processing revolution began. It has
turned out to be more congenial to the study of reading; but most important
to its initial success was the fact that it was there and that it represented a
viable alternative.

Most scientific revolutions affect only the scientists whose old paradigm is
replaced. Occasionally, however, enough sources of dissatisfaction with
prevailing views come together to produce a seismic change in the general
orientation, ideology, and activities of many scientists. A rare and very special
type of scientific revolution changes even society's conception of man and the
universe he inhabits. During the Copernican revolution, people's conception
of their universe changed so that the sun rather than the earth came to be
regarded as the center of their planetary system. The Copernican revolution
also changed our view of how theories are "proved"; it was the scientific
revolution. By believing Copernicus, Western society first accepted the view
that observation and logic, not religious authority, should validate accounts
of reality. In biology, the rise of Darwinian theory during the last century and,
more recently, the ascendence of molecular biology are other examples of encompassing scientific revolutions. Freud presided over one such revolution in psychology, as did John Watson over another. In all of these examples, revolutionary conceptions of man and his universe spread through society. They profoundly influenced institutions outside of science: the church, the law, the educational system, politics, child-rearing, and so on (Segal & Lachman, 1972).

D. Paradigms in Psychology

Thomas Kuhn's ideas about paradigms and different kinds of science is gradually developing an enormous impact on how scientists think about themselves and their institutional enterprise. His views have also been extended and clarified by others. Masterman (1970), for example, has argued compellingly that paradigms play somewhat different roles in different sciences. She implies that there is a kind of developmental sequence of scientific disciplines. In the early days of a discipline, there is nonparadigmatic science: All facts are equally relevant; there are no overriding commitments to a particular conception of subject matter, to a particular method of study, or to a particular set of concepts. As the discipline develops, it becomes multiparadigmatic. Many paradigms vie simultaneously for the attention of the scientific community. Sometimes the different paradigms interact and influence one another; sometimes they do not. But eventually, in Masterman's scenario, one paradigm comes to dominate the discipline. This sets the scene for a scientific revolution. A new paradigm comes to challenge the prevailing one, and "a rank outsider with rudimentary new techniques may succeed in easily solving the major problems of the old paradigm (Masterman, 1970)."

This account describes science in a general way, but the real world is a bit more complicated. Certain branches of science may remain permanently multiparadigmatic. Several relatively dominant paradigms may maintain large constituencies and control most of the journals and meetings of the science. All the while, a number of less influential paradigms will continue to exist. This is now the state of science in psychology, and it may always be this way. The very early history of psychology may have been nonparadigmatic, but there have been multiple psychological paradigms since at least the turn of the century (Weimer, 1974; Weimer & Palermo, 1973). In our field, some paradigms simply change their relative dominance. Until the rise of Watsonian behaviorism, several paradigms claimed the allegiance of different groups of psychologists. Behaviorism appealed to more and more researchers until, by 1940, a variant called neobehaviorism had become the most dominant and popular approach to psychology. The dominance of neobehaviorism lasted for roughly 30 years, but no single paradigm replaced it. Today, psychology encompasses many paradigms, each of which is
popular with a large identifiable group of scientists. The information-processing approach to cognition is one of these, and its influence is substantial.

III. CHARACTERISTICS OF PARADIGMS

By now it may have occurred to you to ask whether paradigms are theories. They are not, even though major paradigms are often associated with particular theories. The Newtonian paradigm and Newton's theory of celestial and terrestrial mechanics illustrate the difference. The theory described and predicted the motions of the planets in our solar system and described the interaction of bodies on earth. Its subject matter was thus only a part of what concerned physicists. The Newtonian paradigm suggested, for the whole field of physics, which problems were important, how they should be studied, and what concepts would most advance knowledge. Its basic concepts of absolute space, absolute time, and absolute motion were not replaced until the Einsteinian revolution. The Newtonian paradigm far outlasted Newton's theory. Newton's theory of the motions of physical bodies had been revised and updated many times—for example, by William Rowan Hamilton and Carl A. Jacobi in the nineteenth century and by Joseph Louis Lagrange in the eighteenth. But the Newtonian paradigm continued to influence all physical sciences for over 200 years. By 1900, physicists had materially changed their factual statements about planetary motion, but their paradigm was what it had been for nearly three centuries. Shortly thereafter, the paradigm of physics changed as well.

How can one psychological paradigm be distinguished from another? Paradigms can differ in several ways, although they sometimes differ in only one or two. A psychological paradigm can be identified by its intellectual antecedents, by its pretheoretical ideas, by its subject matter, by the concepts and language that its adherents use, by their preferred analogies, or by the methods and procedures that its scientists employ. Paradigms are also sociological phenomena. They arise around groups of scientists who communicate mostly with one another. When a group of scientists communicate frequently and are aware of and cite one another's research, they very likely share a paradigm. Let us now look more closely at the characteristics of psychological paradigms. We use these characteristics in the next three chapters when we describe the information-processing paradigm.

A. Intellectual Antecedents

We said earlier that the nature of a science at any point in time is comprehensible and interesting largely in view of its intellectual antecedents. A scientist's beliefs about his work are frequently dictated by his intellectual
predecessors. Paradigms, then, can be distinguished by the intellectual antecedents of their adherents. These antecedents can be historic or contemporary. They are the sources of concepts and views that the scientist applies to his work. Scientists often borrow ideas from mathematics, philosophy, and other sciences, and the disciplines from which a paradigm has borrowed are its intellectual ancestors. Freudian psychology borrowed heavily from medicine. Behaviorism was strongly influenced by British associationism and the philosophy of logical positivism. Information processing has drawn extensively on concepts from engineering, computer science, and communication science.

B. Pretheoretical Ideas

Because sciences have intellectual antecedents, the scientist does not approach his subject matter naively, even if it is a new subject matter about which very little is known. In formulating questions that he might answer scientifically, the scientist draws on notions about the reality underlying his subject. His notions may come from earlier observations, from knowledge about other phenomena that he thinks are similar to his area of study, from well-established beliefs passed on to him from his teachers, or perhaps from his own idiosyncratic insight. Every scientist depends on a network of notions, which Holton has called *themata* (Holton, 1973, 1975). We prefer the term *pretheoretical ideas* because that term has been employed previously in the psychological literature. Pretheoretical ideas guide research, motivate scientists, and sometimes constrain their efforts. Themata, or pretheoretical ideas, are present in most concepts, methods, and propositions of science. They manifest themselves in each of the other dimensions of paradigms: their subject matter, concepts, analogies, and so on.

The pretheoretical ideas of cognitive psychology make up much of the next two chapters. Perhaps the best way to provide a preliminary sense of what we mean by pretheoretical ideas is through an example. To make it easier to distinguish our sample idea from validated scientific theory (which many pretheoretical ideas ultimately become), we will use an idea that proved incorrect. The work of Johannes Kepler provides such an example. Kepler was an astronomer who lived when planetary mechanics was a new science. To the study of planetary movements, Kepler brought his concept of the way things really were:

The perfection of the world consists in light, heat, movement, and the harmony of movements. These are analogous to the faculties of the soul: light, to the sensitive; heat to the vital and the natural; movement, to the animal; harmony, to the rational. And indeed the adornment of the world consists in light; its life and growth in heat; and, so to speak, its action, in movement; and its

This notion of a universe characterized by harmony served Kepler as a pretheoretical idea. It suggested to him that planets traveled in circles, since circles are more harmonious than ellipses. His data were Tycho Brahe's observations of planetary motion, which did not immediately support the idea of circular orbits. However, for 19 years Kepler sought combinations of circles that would give him an orbit for the planet Mars that could be reconciled with Brahe's actual observations. He worked for all those years without success, and eventually he gave up the pretheoretical idea of circularity. Ultimately, Kepler himself demonstrated that it was much simpler to suppose that the planets actually traveled in elliptical orbits.

Incorrect pretheoretical ideas are easier to identify as conventionally derived than correct ones. However, our illustration should not suggest that such ideas are always—or even usually—wrong. Even those that do not seem to fit the data may not be wrong. An example of an extremely influential pretheoretical idea was the unshakable commitment by R. A. Millikan to an atomistic conception of electricity. Millikan lived early in this century, and his belief that electrical phenomena were the result of the actions of discrete elements, which we now call electrons, predated any experimental verification and was maintained in the face of indifferent data (Holton, 1973). Ultimately, Millikan conducted confirming experiments that gave his pretheoretical ideas an enduring scientific acceptance, unlike Kepler's idea of circular orbits.

Pretheoretical ideas operate in all sciences, and each paradigm within a science can be identified by its pretheoretical ideas. In information-processing psychology, most researchers believe that new inputs and old knowledge are represented in some "format" within the system. This pretheoretical idea is reflected in many of our theories involving formulations about the nature of mental searches, recoding of input into different formats, and internal-comparison operations.

A scientist's pretheoretical ideas are his conception of the reality underlying his subject matter. These ideas guide his definition of his subject matter by suggesting what are, and what are not, instances of the phenomena he wishes to study. They suggest what questions should be answered: For information-processing psychology, proper questions concern how information is represented, the nature of its code, how searches proceed, how "matches" are determined, and so on. By suggesting the questions, pretheoretical ideas often also suggest an appropriate methodology for obtaining the answers. Pretheoretical ideas often derive from a preferred analogy—a notion that one's science involves a reality similar to some better understood phenom-
enon. This in turn often suggests that terminology borrowed from the better understood area will be appropriate to the borrowing science as well. As you can see, then, the elements of a paradigm are not independent of each other; they function together as an interrelated system of ideas and concepts that give a scientist a particular "slant" on his field of study. We separate these elements for analytical purposes, but keep in mind that they are component pieces of a picture, each of which involves the other.

C. Subject Matter

Choosing a subject matter amounts to deciding what questions should be answered—selecting those questions whose answers seem to promise the most complete account of the natural system under study. In psychology, the natural system is the behavior of living creatures, especially human beings. Some psychologists believe that the most important aspect of people is their personalities. These researchers are likely to study individual differences, or people whose personalities are deviant. Others believe that learning is the most fundamental characteristic of living organisms, and they are apt to study how people and other animals acquire new responses. These psychologists will tend to overlook individual differences, and are usually more interested in typical performance than in extraordinary circumstances. Still other psychologists are interested in how people use language. They also are less likely to study individual differences, and are usually more interested in normal performance than deviant linguistic behavior.

The same questions recur continually within a conventional or paradigmatic group. While its choice of subject matter does not always define a particular paradigm, different paradigms are often best suited to the study of different subjects and hence become closely associated with them. Cognitive psychology is coming to be identified with the information-processing paradigm, because it has proved more successful than others in advancing our understanding of the higher mental processes.

D. Analogies

When scientists turn to the study of things they know little about, they often borrow principles from better-understood areas to guide their new research. When physicists first began to study gases, they borrowed principles from mechanics, postulating that gases were composed of something that behaved much like billiard balls or planets. Consequently, long before we understood molecules, the molecular action of gases was characterized with the same principles that accounted for the motion of visible bodies. Physicists could have used an analogy to some other phenomenon, such as ocean waves, and it would have misled them.
Analogies are also used to develop psychological theories. In Freud's psychoanalytic theory, sexual energy is viewed as a hydraulic system. According to this view, a person is subject to internal pressures that require release; if one outlet is plugged, the pressure will find another. This analogy directly underlies the psychoanalytic view of symptom substitution: If a patient's symptom is removed, but his basic personality remains unchanged, another symptom will appear to take its place. Freud's use of such analogies probably resulted from his medical training, according to which bodily organs were considered analogous to mechanical devices, such as pumps and levers. A paradigm's preferred analogies influence its choice of research questions, suggest hypotheses for experimentation, and help in theory construction. Different paradigms typically rely on different analogies.

E. Concepts and Language

Adherents of a paradigm often borrow terms from other disciplines, but they also invent terms to handle the concepts and data peculiar to their paradigm. There is some overlap between the languages of different paradigmatic groups, but each usually has a set of terms unique to it. These terms include names for conceptual entities and processes. Some people argue that this difference in language is "just semantic." They believe that the language of one paradigm is interchangeable with the language of another. It has been argued that it makes no difference whether a scientist says stimulus or input, whether he says response or output when referring to the conditions under which people behave and what they do. According to this view, all of the terms are mere jargon. We disagree. It seems to us that the terms that scientists use reflect their beliefs about the basic properties of the system they are studying. A psychologist's terminology often reflects fundamental conceptions of people and their capacities. Referring to behaviors as outputs rather than as responses implies very different pretheoretical ideas about the mechanisms underlying behavior.

F. Research Methods

The adherents of different paradigms often use different research methods. The paradigmatic, conventional component of science often includes preferences for particular pieces of apparatus, for particular experimental designs, for particular independent and dependent variables. Information-processing psychologists show a preference for human subjects and temporal measures, often using tachistoscopes and reaction-time data. They vary such factors as stimulus complexity and task demands; they control such matters as grammatical complexity and stimulus probability. These preferences, and the reasons for them, are developed in the next two chapters. They are not the
only methods one could use, but they reflect the influence of the information-processing paradigm. Such methodological preferences are not perfect clues; but they often distinguish one paradigmatic group from another.

IV. PARADIGMS, INFORMATION PROCESSING, PSYCHOLOGY, AND SOCIETY

A paradigm reflects the thinking of a community of scholars who talk largely to one another, cite one another's findings, and do similar work. Paradigms are basic intellectual commitments about how to do a science, about the importance of different problems, about what are "facts" and what are not, about language and concepts that are appropriate, and about the suitability of different kinds of theory to a subject matter. Many paradigms can exist simultaneously in a given science, and in psychology several do. There certainly are differences among psychologists adhering to a given paradigm, but the similarities of their commitments outweigh the differences among them. Differences among paradigms are sometimes cast as issues of which is more scientific, but paradigmatic variations are far more subtle and more complex than that. Consider the metaphor of driving from New York to California. Many routes will get you there; no single way is absolutely correct. Some ways are more efficient than others; some are more beautiful; some are safer. People impose order on their world in their efforts to understand it; and it is impossible to absolutely value any single ordering scheme above all others. Nature can be ordered in many ways.

We have written this book from the point of view of one particular paradigm—information processing. We do not argue that it is the right way to understand and explain human mental processes, but we believe that it is at the present time the most comprehensive and comprehensible way. The recent ascendancy of information processing is a significant change in the study of higher mental processes. The change was essentially paradigmatic; it concerned man's basic character as well as theories of how he thinks. The information-processing paradigm made new questions interesting; it applied a new language to man's mental processes; it suggested new analogies for research into cognition; and it used some basically new techniques. This paradigm has potential applications beyond cognitive psychology—in clinical, social, and educational psychology, for instance. We would not be surprised to see the information-processing paradigm influence all of psychology. If it extends to the larger society as well, many people's conception of human nature will be affected.

It usually takes years for a change within science to affect the larger society. By now, most people have heard of Freud, but his impact on specialized psychology came over 50 years ago. Popular novels, child-rearing guides, and
other printed materials now incorporate Freudian ideas, as if they were highly regarded and very contemporary among today's scientists. They are not; not many people realize how few courses in Freudian psychology are offered in most psychology departments today. The principles of behaviorism have been taught much more extensively over the last 40 years, but the general public knows far less about them. Some well-educated people have a general understanding of conditioning, but most do not. Information processing, which has been academically significant for 15 or 20 years, is still virtually unknown even to educated lay people. Students may come to college with a layman's acquaintance of approaches that may be 50 years behind events in particular sciences. In studying the contemporary literature, they must often leap over many years of thought within the science to catch up with prevalent paradigms. It is important for students to do this, both for themselves and for society at large. If only practicing scientists understand them, the newest paradigmatic developments will have little influence on society in general.

Even if we are wrong, and information-processing views never affect nonscientific social institutions, cognitive psychology has been profoundly influenced by the information-processing approach. Cognitive psychology is now identified as strongly with information processing as it is with the study of higher mental processes. The best way to understand this book and the field it deals with is to grasp the essentials of the information-processing paradigm. That understanding will make it much clearer why many researchers chose to do the experiments they did, and why they chose to do them as they did instead of some other way.

This book is designed to provide a thorough introduction to information-processing psychology. Chapters 2, 3, and 4 present in detail the characteristics of the paradigm and how it attained these characteristics. Later chapters present theory and data. As with all research sciences, the data are fragmented. The experiments will not answer all of your questions, as they have not answered all of the questions of the scientists who did them. But the studies represent what the science knows, where it is going, and how it expects to get there. The reader is not left to grapple alone with the fragmentation. Each chapter answers several of these organizing questions: Why are the contents of the chapter important? What do they mean to cognitive psychologists? What do the contents of the chapter add to our picture of humankind? How has the information-processing paradigm influenced the experiments discussed? We are convinced that if you learn the concept of a paradigm and the properties of the information-processing paradigm, you will be better able to tie together research on man's higher mental processes. Many students have used these ideas to make sense out of their other science courses as well.
References


Bever, T. G., Lackner, J. R., & Kirk, R. The underlying structures of sentences are the primary units of immediate speech processing. Perception and Psychophysics, 1969, 5, 225–234.

REFERENCES


REFERENCES


REFERENCES 537


Efron, R. The minimum duration of a perception. *Neuropsychologia*, 1970, 8, 57–63. (b)

Efron, R. Effect of stimulus duration on perceptual onset and offset latencies. *Perception & Psychophysics*, 1970, 8, 231–234. (c)


REFERENCES


Estes, W. K. Some targets for mathematical psychology. *Journal of Mathematical Psychology*, 1975, 12, 263–282. (a)


REFERENCES


REFERENCES 543


REFERENCES

Kuhn, T. S. *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press, 1970. (a)

Kuhn, T. S. Logic of discovery or psychology of research? In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of knowledge*. London: Cambridge University Press, 1970. (b)

Kuhn, T. S. Reflections on my critics. In I. Lakatos & A. Musgrave (Eds.), *Criticism and the growth of knowledge*. London: Cambridge University Press, 1970. (c)


Lachman, R. Uncertainty effects on time to access the internal lexicon. *Journal of Experimental Psychology*, 1973, 99, 199-208.


REFERENCES


Miller, G. A. The magical number seven, plus or minus two: Some limits on our capacity for processing information. Psychological Review, 1956, 63, 81–97.


REFERENCES


REFERENCES


REFERENCES


Pribram, K. H. *Why a neuropsychologist must know the literature in memory, perception and cognition as well as physiological psychology*. (To be published by Lawrence Erlbaum Associates.)


550 REFERENCES


Schendel, J. D. Analysis of the rehearsal processes in the release from proactive interference. *Journal of Experimental Psychology: Human Learning and Memory*, 1976, 2, 76-82.


REFERENCES


REFERENCES


Sperling, G. The information available in brief visual presentations. *Psychological Monographs*, 1960, 74(Whole No. 11).


Sternberg, S. *Decomposing mental processes with reaction-time data*. Invited address, Midwestern Psychological Association, Detroit, May 1971.


REFERENCES


Wertheimer, M. Untersuchungen zur Lehre von der Gestalt. II. Psychologische Forschung, 1923, 4, 301–305.


Wright, P. Some observations on how people answer questions about sentences. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 188–195.


