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ABSTRACT

The current status of conceptions of learning in children is reviewed and some areas of neglect are considered in this paper. The main premise is that although considerable strides have been made in the understanding of the learning process, essential developmental formulations of growth and change have been poorly articulated. It is suggested that there has been overreliance on the dominant theories of adult cognition and a return to a consideration of developmental issues within a framework of comparative psychology is advocated. Preliminary steps for a revived theory of development and learning are described, including a consideration of such topics as compatibility or naturalness, accessibility and flexibility of learning, and processes of induction. A three-pronged attack on the investigation of essential features of learning is suggested that involves: detailed specification of developmental progressions and trajectories within a domain, microgenetic considerations of learning within a subject over time, and engineering change via the intervention of supportive others. (Author/MKM)

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LEARNING AND DEVELOPMENT: THE PROBLEMS OF COMPATIBILITY, ACCESS, AND INDUCTION

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Abstract

The purpose of this manuscript is to review the current status of conceptions of learning in children and to consider some areas of neglect. The main premise is that although we have made considerable strides in our understanding of the learning process, essential developmental formulations of growth and change have been poorly articulated. Overreliance on the dominant theories of adult cognition is implicated and a return to a consideration of developmental issues within a framework of comparative psychology advocated.

Preliminary steps for a revived theory of development and learning are described. These include a consideration of such topics as compatibility or naturalness, accessibility and flexibility of learning, and processes of induction. A three-pronged attack on the investigation of essential features of learning is suggested. This would include: (a) detailed specification of developmental progressions and trajectories within a domain, (b) microgenetic considerations of learning within a subject over time, and (c) engineering change via the intervention of supportive others.

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Learning and Development: The Problems of Compatibility, Access, and Induction

My main purpose in this paper is to give a brief summary of the state of the art in the field of memory development, concentrating on the sophistication of our understanding of the problems now compared with a decade ago. I would then like to consider some neglected issues concerning developmental constraints on learning and problems of growth and change that are largely ignored in our theories of memory as they currently stand.

The general topics I will address can most parsimoniously be summed under the title learning. This may come as somewhat of a surprise since contemporary cognitive developmentalists, myself included, appear to go to extraordinary lengths to avoid using the word learning at all. It is not merely a problem of elaborate synonym substitutions; we no longer seem to have an area called learning at all. For those who are made uncomfortable by the term, I suggest that you substitute the compound memory-and-comprehension for learning in the first part of the paper, an awkward practice that is commonly observed by writers in this area, then gradually fade in the term learning proper in the second half of the paper, where its somewhat distinct meaning from "memory-and-comprehension" will be emphasized.

In the first part of the paper, I will concentrate on the enormous gains we have made in the last decade in developing a rich description of the development of academic skills. The importance of learning theories, computer metaphors, and schema models in helping us develop that picture will be emphasized. In the second part, I will consider developmental psychology as a branch of comparative psychology and will focus on some tricky problems of growth and development that our dependence on computer metaphors and traditional learning models has led us to underrepresent.

If one considers some commonly agreed upon theories of learning that have emerged in the last decade, a skeletal prototype can readily be extracted--that is, it could be if one were able to locate the pertinent literature, for rarely does the term learning appear undisguised in the title. The most extensive treatments have been made by developmental psychologists interested in memory and by cognitive psychologists under two guises, cognitive science and instructional psychology; the cast of characters remains the same, but the title changes depending on whether they are presenting applied or basic personas. According to these sources, the acquisition of expertise (or the development of memory) involves the development and refinement of four interrelated forms of knowledge, factual knowledge and strategic knowledge, both of which can be subdivided into domain-specific and general. Let me emphasize that the "theory" I am about to describe is by no means uncontroversial, and is far more simplistic than any real existing theory. The prototype theory is meant merely to illustrate some problems with the state of the field.

The prototype theory goes something like this: novices differ from experts (younger children from older ones, slower learners from brighter ones) in terms of their repertoire of strategic skills and their factual information. Some of the knowledge that is acquired through experience is domain-specific and some transcends any particular problem or subject area. Consider first factual knowledge. Increasing expertise involves not only the accumulation of more facts but the tighter organization of the information into chunks, categories, scripts, frames, schemata, networks, etc., depending on one's theoretical predilections. Concomitant with the greater organizational coherence is faster access to accumulated knowledge via multiple alternate pathways, more elaborated connections, redundant couplings, densely clustered networks, hierarchical-categorical systems, etc. --again according to one's theoretical biases and preferred terminology.

Consider next strategies. Experts have greater strategic knowledge than novices and again that knowledge can be both general problem-solving know-how or it can be domain-specific procedural knowledge. General strategies include the kinds of self-management, self-inquiry routines that developmental psychologists have called metacognitive skills (Brown, 1975, 1978; Flavell, Note 1) or metastrategies (Chi, in press), and cognitive psychologists are coming to call metastatements (Anzai & Simon, 1979), or metacomponents (Sternberg, 1980). These include monitoring, checking, planning, revising, reality testing, etc. (Brown, 1978; Brown & DeLoache, 1978) but also such things as means-end analyses, strategic goal path selection, etc. Specific strategies obviously depend on the task, and most descriptions of learning in semantically rich, formal domains of knowledge involve the specification of specialized strategies and procedures for operating within that domain.

In short, experts differ from novices in that they know more--they knows more pertinent facts, their knowledge is better organized, they have more strategies to guide performance and ensure cognitive economy in their domains of expertise, and the mature expert may have more transsituational strategies for problem solving in general. I would like to argue that despite the appearance of this coherent, agreed-upon theory of learning, what we have in the prototype theory is open to the criticism that it is trivial. One reason it is open to this criticism is that the average child on the street would come up with a description very similar to the prototype (Brown & Chi, Note 2). Another, more serious, criticism is that not only is the theory self-evident but it is silent, or at least obscure, concerning how gains in expertise come about (Brown, 1979). Although we would all agree that the expert (older child, etc.) knows more facts and has more strategies, we have very little to say about how the expert made the transition from novice. And, embarrassing as it may be for developmental psychologists, we have little to say about what might be the major differences between the child and the adult novice. I will return to these questions later, for I would like to begin by emphasizing the advances we have made rather than concentrating on issues we have difficulty addressing. To do this, I would like to introduce a simple little learning model.

A Simple Little Learning Model

The larger part of developmental memory research conducted in the late sixties and throughout the seventies has led to the establishment of a fairly detailed picture of how the child becomes a school expert; i.e., how the young learner acquires academic skills and comes to know how to learn deliberately (Brown, 1975, 1978; Bransford, Stein, Shelton, & Owings, 1980).

Insert Figure 1 about here

To illustrate the current state of our knowledge, I would like to introduce the diagram in Figure 1, which I borrowed from Bransford (1979) who in turn borrowed it from Jenkins (1979), who used it to illustrate a tetrahedral model of memory. At first glance this seems like a simple little model, particularly in comparison with the elaborate flow diagrams favored by modern cognitive psychologists imprinted on the computer in their formative years. Unfortunately, as is usually the case in psychology, the simple little model becomes more complex on closer examination. But it does provide a useful aid to help us consider the major factors that must be taken into account when considering any aspect of learning or remembering. Let me stress that not only must we, the psychologists, consider the tetrahedral nature of the learning process, but this is exactly what the expert learner must come to consider.

The diagram is meant to represent the learning situation, i.e., the learner-in-context. There are a minimum of four factors that comprise the learner-in-context, and these factors interact in nontrivial ways. First I will consider the four factors independently, and then describe some two-way interactions, hint at some three-way interactions, and stop there. Anyone who knows about interpretation of four-way interactions will guess why. But this progression, from looking at one aspect of the learner in context to considering increasingly complex interactions, mirrors the progression of our theory development in the area of learning. The four minimum factors are 1) the learner's activity, 2) the characteristics of the learner, 3) the nature of the materials to be learned, and 4) the criterial task: what end product is required from the learner? I will give only a few brief illustrations of the types of factors that have been considered under each of these rubrics and then provide a few randomly selected examples of the interactive nature of the model (for more detailed treatments of the adult literature, see Bransford, 1979; Jenkins, 1979; and for the developmental literature, see Brown, Bransford, & Ferrara, in press).

Learning Activities

One of the most established facts in developmental theory is the active strategic nature of learning. We have a very rich picture of the development of strategies for learning and remembering and quite convincing evidence that efficient performance in a wide variety of tasks is in large part dependent on the appropriate activities the subject engages in while learning, either on his own volition, when trained to do so, or even when tricked into doing so by means of a cunning incidental orienting task. As children mature, they gradually acquire a basic repertoire of these skills, first appearing as isolated task-dependent actions but gradually evolving into flexible, generalizable skills. With extensive use, strategic intervention may become so dominant that it takes on many of the characteristics of automatic and unconscious processing, in that only intensive introspective questioning can reveal the operations of the strategic device even to the operator (Brown, 1975, 1978, 1979; Brown & Campione, in press).

Under instructions to remember, the mature learner employs a variety of acquisition and retrieval strategies which are not available to the developmentally less mature individual. There is also an implicit assumption that there exists a hierarchy of strategies from simple processes like labelling and rote rehearsal, to elaborate attempts to extract or impose meaning and organization on the to-be-remembered material. Indeed, one outstanding feature of mature memorizers is the amazing array of complex transformations they will bring to even the simplest laboratory task. Developmental differences are determined in part by the degree to which increasingly complex strategic skills can be applied. Finally, whereas it may be possible to distinguish certain basic skills children must acquire, once they have mastered these it is no longer possible to define an optimal task strategy, for the optimal strategy for any one subject will depend on that subject's success or failure with previous strategies, estimation of his or her own capabilities, creativity, certain personality variables, in fact, the subject's personal cognitive style (Brown, 1975).

Although this is one area where we have been very successful at providing a rich description of development, there are still some holes in the picture. The most notable one is the relative absence of a detailed consideration of the early emergence of plans and strategies of learning. Although there is increasing activity in this area (DeLoache & Brown, 1979), it is still true that our knowledge about early cognition, other than language development, is extremely limited and rather negative, consisting of many more descriptions of what young children cannot do, than of what they can do (Brown & DeLoache, 1978). Rochel Gelman (1978) gives examples of exceptions to this rule and compelling reasons why we arrived at this position.

Briefly, we have been concerned primarily with the competencies that define the school-aged child, specifically the shift to more adequate understanding that occurs at between 5-7 years. To illustrate with an example from the memory literature, until recently the bulk of studies concerned rote learning of lists and the emergence of rehearsal or categorization as tools to enhance performance. These strategies tend to emerge in a recognizable form at about 5 and are well established by about 8 years of age. This fact has placed a limitation on what we have learned about the early development of strategic intervention. Probably the most important deficiency is that the tasks are set up in such a way that we cannot say anything about nonproducers; if children are not, for example, rehearsing on our task, we have no way of knowing what it is that they are doing.

Apart from providing a baseline from which improvement with age can be measured, the inclusion of the younger or less efficient group in these enterprises provides little information. These children perform poorly, and therefore highlight the improvement with age we wish to demonstrate. But we know nothing about their state of understanding. They are characterized as not being at a certain level, of not having a certain attribute; they are nonproducers, nonconservers, nonmediators; they are not strategic or not planful; they lack number concepts, reversible operations, or transitivity, etc. They are sometimes described as passive, even though the tasks are designed so that the only way to be characterized as active is to produce the desired strategy. All of these descriptions are based on what young children do not do compared with older children, rather than what they can do; for we have no way of observing this in the confines of the tasks selected for study (Brown & DeLoache, 1978; Gelman, 1978).

The resultant picture of memory development then is a virtual wasteland in our knowledge of how memory develops after the first 8 months or so (Cohen, DeLoache, & Strauss, 1979) and before the infamous 5-to-7 shift (Brown & DeLoache, 1978; White, 1965). This is an unfortunate lack for several major reasons. First, there is the obvious reason that a theory or even a description of human growth cannot begin to be complete if it is silent on development during a period of extremely rapid growth. Second, a case could be made that early learning not only forms the basis of later learning but is in some sense qualitatively different from later learning. The strong instantiation of this claim would be a version of the critical period notion, a weaker form would be more akin to Hebb's (1958) famous distinction between early and late learning. I will return to the primacy of early learning later, but it does seem unfortunate that we have little empirical evidence or theoretical speculation concerning early learning comparable to that of theorists working in language development (Newport, in press; Slobin, 1977).

The third reason that this lack of information about early learning activities is to be regretted has to do with social policy. Federal Law 94-142 mandates that school districts be responsible for the education of the handicapped from age 3 onwards, and compulsory screening for cognitive deficits is being established nationally. It is not clear to me how one can screen intelligently for early signs of aberrant development without an adequate picture of what is normal.

The Characteristics of the Learner

The repertoire of strategic activities that a learner can bring to the learning context is only one characteristic of the learner that is relevant and influential to our tetrahedral model. Learners vary in what they know and what they can do, and these factors must influence how they learn. The factual and strategic information of the knowledge base obviously interacts in non-trivial ways (Chi, in press), and the problems of how the knowledge base grows, changes, and reorganizes are the quintessential developmental questions.

What do our current information processing models have to say about the knowledge base? First, the knowledge base is seen as the repository of rules, strategies, and operations which can be used to make more efficient use of a limited capacity system; young children and novices have not yet acquired a rich repertoire of these routines, as we saw above. In addition, the child's knowledge base is said to be deficient in at least three ways: (a) the amount of information it contains, (b) the organization and internal coherence of the information, and (c) the number of available routes by which it can be reached. These differences impose several limitations on the child's information-processing abilities. Such basic cognitive processes as speed of encoding, naming, and recognition (Chi, 1976) are all influenced by restrictions imposed by an impoverished knowledge base. Although this is undoubtedly true, we are still far from achieving insights into qualitative growth mechanisms. How does the system become rich, rather than impoverished, if by that we mean more than a mere accumulation of facts? How does the organization and internal cohesion of information change qualitatively with age?

And then there is the problem of capacity! A major characteristic of the learner is his working memory capacity. While few would doubt that the human information processor is restricted by a limited working capacity (see Neisser, 1976, for discussion, however), and that children functionally are more restricted by capacity limitations than adults, there is considerable controversy concerning whether capacity per se (rather than use of capacity) develops with age (Chi, 1976; Huttenlocher & Burke, 1976). Again, although we have made great strides in describing functional capacity limitations in children, the essential developmental issue of whether there are age changes in capacity per se is open to debates of some complexity.

Another characteristic of the learner that must enter into the learner-in-context equation is self-knowledge, including the learner's knowledge about his or her own cognitive competence--one of the characteristics of the learner examined by those developmental psychologists interested in metacognition (notably Flavell, 1971a, Note 1). I will return to this topic

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later. Still missing from this somewhat casual list of the learners' characteristics is any mention of emotional factors such as attitudes, opinions, beliefs, prejudices, fears of failure, etc., all important factors in determining the efficiency of any learning activity.

Materials to be Learned

Another important influence on effective learning is the nature of the material that must be acquired. Whether there is organization inherent in the material, and if so, the type of organization it is, will clearly influence the learning process. Good exemplars of categories afford the activity of categorization (Rosch, 1979), prose material that is compatible with the reader's preexisting knowledge is more likely to be understood (Anderson, 1977; Brown, 1975; Trabasso, 1980). Stories that conform to canonical form are easily retained (Mandler & Johnson, 1977; Stein & Glenn, 1979). For a detailed review of the importance of organizational factors see Mandler (1979).

Criterial Task

Learning is not undertaken in a vacuum; there is always an end product in mind, and the effective learner is cognizant of this end product and tailors his learning activities accordingly (Baker & Brown, in press; Bransford, Nitsch, & Franks, 1977; Brown, 1978, 1979). Learners need to know whether the demand is for gist rather than verbatim recall, for recognition rather than reconstruction or recall in a memory task (Brown, 1975). They need to know if memory for the material is required as the end product, or whether they will be called upon to apply the acquired information to novel instances (Nitsch, 1977). In short, learners' activities are purposive and goal-directed and the nature of the criterial task will play an important role in determining the effective activity that must be undertaken.

Thus the four points on the figure represent important ingredients in the learner-in-context formula. Indeed it is difficult to talk about them in isolation because the four elements work interactively to determine learning, and it is only by considering the total picture that one can fully understand the learning situation. In the early days of memory development research the focus was usually on just one aspect of the tetrahedron: i.e., is recall easier than recognition (criterial task)? Do strategies develop with age (learning activity)? Is the material to be learned pictures or words (nature of the materials)? Is the material compatible with the learners' prior knowledge (characteristic of the learner)? As our understanding of the complexity of the learner-in-context formula has developed, we see a far greater concentration on the interactive nature of the learning process. Most current developmental work focuses on at least two-way interactions of the model and there are some attempts to consider three-way interactions. Here I will give a few examples to illustrate this greater focus on the interactive nature of learning.

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Interactive Nature of Learning

Let us begin by considering some potential interactions of the knowledge base and the learning activity. One of the basic issues that has guided the emergence of the now popular area of study, metacognition, is that it is not sufficient to "have" (in the sense of be available in the knowledge base) knowledge or strategies, unless one can use them effectively in the learning process. Learners who are not aware of their own limitations, or strengths, or of their own strategic repertoire, can hardly be expected to apply appropriate strategies flexibly, and precisely in tune with task demands. There is considerable evidence of the immature learner failing to capitalize on the resources available to him (Brown, 1978; Flavell, Note 1). And it is quite clear that the information that is "in" the knowledge base is not always used effectively by adults (Gick & Holyoak, Note 3), never mind children (Brown & Campione, in press).

The immature often fail to capitalize on information they have. For example, young children and retarded persons can only with great difficulty be persuaded to use categorical information as a deliberate aid to learning, but this does not mean that their knowledge is not organized categorically. Consider the semantic priming task. In one example of this task, the learner is required to name pictures as rapidly as possible. Sometimes a target picture (cat) is preceded by a conceptually related item (bear) and sometimes by an unrelated item (train). Speed of naming the target is more rapid if it is preceded by a related item. The conceptual category is said to be "primed" by the related, preceding category. Sperber, Ragain, and

McCauley (1976) used a priming task to assess the conceptual knowledge available to retarded individuals and found clear evidence of category organization. The simple category structure is in some sense available in memory although retarded learners are generally quite unable to harness the information in order to design an effective strategy for learning. Similarly, children show release from proactive inhibition upon a change in category membership at a very early age, well before the emergence of categorization as a deliberate memory strategy.

Another form of information that is often available but not necessarily accessible is strategic knowledge, and this is such a common finding in the developmental literature that it has a name--production deficiencies (Flavell, 1970). We do not always employ the appropriate strategies for learning even if we have them available. The immature learner is much less likely to use his or her knowledge appropriately, as is demonstrated in the robust findings of maintenance and generalization failures following strategy training (Brown, 1974; Brown & Campione, 1978, in press). Effective learning, then, is not simply a matter of acquiring the necessary informational background and strategic routines. It is as much a problem of adequate use and control of the routines available to the system--of accessing and using the resources one has (Brown & Campione, in press). I will return to the problem of access later.

Now let us turn to potential interactions involving the knowledge base and the nature of the materials. If there is compatibility between the organization and information in the knowledge base and the organization and information inherent in the material, learning will be enhanced. This is the basic notion behind the concept of headfitting, introduced by Jenkins (1971) and Brown (1975, 1979). The basic premise is that there is an intimate relation between what is currently known and what can be readily acquired. Because we must come to know more with increasing age and experience, there must be a close correspondence between what a child can understand at any point in his life and his concurrent cognitive status. The assumption is that material is comprehensible or not, easily learned or not, to the extent that it maps onto the preexisting knowledge and preferences of the learners. Extreme versions of this approach suggest that if material is highly compatible, understanding will be "automatic" (Brown, 1975; Jenkins, 1974). The ultimate demonstration of the headfitting notion is one that should be readily found in a developmental literature. Ideally, little thinkers lacking some basic knowledge should be hindered in their comprehension of any novel information that presupposes the existence of that prior knowledge. This fact can readily be found in studies that examine children's comprehension of texts (Baker & Brown, in press; Trabasso, 1980).

One nice example of the interactive influence of the knowledge base is the problem of individualized instruction. Quite simply, if one is to instruct a child to perform in a way he previously could not, the most intelligent way to proceed is to find out where he is coming from, i.e., to estimate his starting level of competence. It is a widespread assumption of developmental psychologists of quite divergent theoretical viewpoints that the distance between the child's existing knowledge, and the new information he must acquire, is a critical determinant of how successful training will be. Siegler's elegant rule-assessment approach has been successful in revealing the primitive rules children use before attaining full understanding of a variety of scientific concepts, such as torque, probability, conservation, etc. and of methods of inducing children to apply a more sophisticated rule than their original level (Siegler, in press).

Another nice demonstration of the headfitting notion is Chi's (1978; in press) examples of mature strategy use in little learners who for some reason have well developed knowledge bases, e.g., chess players or dinosaur afficionados. Chi's twist is that in her sample of chess players knowledge is inversely related to age. In general, the children are the experts while the adults are the novices. It is the experts (children) who outperform the novices both in terms of actual memory performance and in predicting in advance how well they will perform--a nice example of the headfitting notion.

As a final demonstration of the interactive nature of learning consider the two-way interaction of <u>learning activities</u> and <u>criterial task</u>. If learning activities are purposive and goal-directed, an appropriate learning activity must be one that is compatible with the desired end state. One cannot, therefore, discuss appropriate learning activities unless one considers the question "appropriate for what end?" A well-known example of this principle is the work on encoding specificity. The compatibility between the context within which material is acquired and the context within which it must be retrieved is an important determinant of retrieval efficiency (Cermak & Craik, 1979).

Bransford and colleagues (Bransford, Franks, Morris, & Stein, 1977) introduced the term transfer appropriate processing to deal with the compatibility between the learning activity and the goal of that activity. Traditionally, learning studies have relied almost exclusively upon accuracy of memory in measuring the success of learning, but this practice can lead one to neglect some important aspects of learning that are necessary for valuable kinds of transfer. Knowledge in a form that permits optimal memory need not be in an appropriate form to be used to understand a novel input (Nitsch, 1977). Several studies from Bransford's laboratory and from our laboratory have adopted the position that if you want to achieve use of knowledge or transfer of training it seems reasonable to concentrate on activities that help people understand the significance of information and its potential use, rather than concentrating merely on rote learning of the information. For example, whereas the mnemonic strategy of imagining bizarre interactive images or elaborated verbal codes is of excellent use in improving rote recall of paired-associate lists, or unusual names or facts, it is not clear that such a technique would be the best one for understanding the meaning of the facts in a passage. If rote recall is the criterial task, mnemonic techniques are of undoubted value. If understanding and use of the relevant facts is the desired end product, activities that focus on clarifying the significance of the facts are much more likely to succeed (Bransford, Stein, Shelton, & Owings, 1980). In

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short, an optimal learning strategy can only be determined relative to the uses to which the acquired knowledge will subsequently be put.

Although I have emphasized some "simple" two-way interactions of the model, I would like to repeat that an adequate characterization of the learning process must consider the complex interaction of all four factors. Learning activities can only be tailored appropriately if the task demands, the nature of the material, and the information in the knowledge base are all considered. For example, consider learning from texts. Any strategy one might adopt would be influenced by the test to which the learning must be put (gist recall, resolving ambiguities, acquiring basic concepts, etc.), the inherent structure of the material (its syntactic, semantic, and structural complexity, its adherence to a good form, etc.), and the extent to which its informational content is compatible with existing knowledge. When one considers this, it is no wonder that developmental cognitive research is becoming more complex.

Expertise

As psychologists we must come to understand the four basic factors of the tetrahedral model and how they interact with each other to influence learning. I would like to argue that this is exactly what efficient learners must do. Before they can become experts, children must develop the same insights into the demands of the learning situation as psychologists. They must know about their own characteristics, their available learning activities, the demand characteristics of various learning tasks, and the inherent structure of materials. They must tailor their activities finely to the competing demands of all these forces in order to be flexible and effective learners. In other words, they must learn how to learn.

Becoming an expert is the process of acquiring knowledge about the rules, strategies, or goals needed for efficient performance. When faced with a new type of learning situation , anyone is a novice to a certain extent and children are universal novices (Brown & DeLoache, 1978). Novices often fail to perform efficiently not only because they may lack certain skills but because they are deficient in terms of self-conscious participation and intelligent self-regulation of their actions. The novice tends not to know much about either his capabilities on a new task or the techniques necessary to perform efficiently; he may even have difficulty determining what goals are desirable, let alone what steps are required to get there. Note that this innocence is not necessarily age-related, but can merely be a function of inexperience in a new problem situation. Adults and children often display similar confusion when confronted with a new problem: Chi's (1978) novice chess players (adults) have many of the same problems that Markman's (1977) very small card players experience. For both, the situation is relatively new and difficult. Barring significant transfer from prior experience, the beginner in any problem-solving situation has not developed the necessary knowledge about how and what to think under the new circumstances.

We are beginning to see in the literature many examples where the acquisition of expertise in a domain by adults looks very similar to the development of academic learning skills by children (Brown & Chi, Note 2).

Indeed one might reasonably ask what developmental psychologists have to say that is uniquely developmental, i.e., what is it that we study other than the acquisition of expertise, which could quite easily be studied by considering the passage from novice to expert in adult subjects? As developmental psychologists, if we cannot answer that question, we are again admitting that essential formulations of cognitive growth across the life span have not been well articulated. What does distinguish the child from the adult novice? Note that in considering the tetrahedral model, the term age need never occur, a problem that has led to the self-conscious use of joint terms like age-and-experience to denote expertise.

In the preceding sections, I have concentrated on what we know about the learning situation as psychologists and what the child must come to know in order to be an expert learner. I have argued that indeed we do know a great deal about the constraints on learning that derive from a deficient knowledge base and inefficient use of a limited capacity system. I have pointed out that we can characterize the demands of a learning situation quite adequately, pinpoint problems of the novice, and describe the developmental progression towards expertise. Although we have made extraordinary strides in our ability to describe the course of cognitive growth, we have lagged behind in our ability to characterize the nature of the growth process itself. Most of our theories of growth either ignore the fundamental issues of change and development or are extremely vague about the topic. Mechanisms that promote change and growth are the essential issues of a theory of human learning (Brown, 1979). In the next section, will speculate about some of the reasons why developmental psychologists have been less concerned with essential learning and growth issues than one might expect.

Models of Psychology and the Questions of Growth and Learning

Although many would agree with Neisser (1976) that "No theory that fails to acknowledge the possibility of development can be taken seriously as an account of human cognition" (p. 62), there are historical reasons why consideration of developmental issues has been constrained, and I would like to trace some of these briefly here. It is often claimed that one of the things wrong with developmental psychology is that insufficient attention is paid to theories of adult cognition. However, for the sake of argument, I would like to make a strong counterclaim that historically we have been overly influenced by the fashions of experimental psychology.

Consider the adult models available for us. The history of mainstream psychology in this country has been dominated by three major movements: the macro-model learning theories, the computer metaphors of information processing, and the recent schema-theoretic formulations. These movements have been extremely influential and have spawned powerful derivative theories for those interested in children's learning. But they have characteristic features that make them improbable models for a science of human growth.

<u>Traditional Learning Theories</u>

The prototypical examples of the all-encompassing learning theories are those of Hull (1943), Skinner (1938), and Tolman (1932). Although the critical differences between these theories were sufficiently compelling to occupy empirical psychology for thirty years, they also share common features that make them less than ideal models for developmental psychology. All derived their primary data base from rats and pigeons learning arbitrary things in restricted situations. All three hoped that their systems would have almost limitless applicability. True to a creed of pan-associationism, they shared a belief that laws of learning of considerable generality and precision could be found, and that there were certain basic principles of learning that could be applied uniformly and universally across all kinds of learning and all kinds of species. These principles were thought of as species-indifferent, activity-indifferent, and context-indifferent.

The theories had very little to say about species variation. Attempts were made to place animal species (also humans differing in age) on a ladder of increasing intellectual capacity. For example, fish were designated less intelligent than rats because they displayed less of a certain type of learning (Bitterman, 1965). But the skills selected as measures of intelligence were quite arbitrary (species-independent), as indeed were the situations selected in which to test the presence/absence of the skills (e.g., impoverished environments where the skills to be learned had no adaptive value for the species in question). In summary of this type of enterprise, it has been said (Rozin, 1976; Schwartz, 1974) that by studying the behavior of pigeons in arbitrary situations we learned nothing about the behavior of pigeons in nature, but a great deal about he behavior of people in arbitrary situations.

The theories had very little to say about developmental issues. The growth of the knowledge base was simply incremental. Although later there were some attempts to deal with reorganization of small basic units into larger complex forms, it was by no means dominant in these theories, and by no means an unqualified success. Children learned by the same rules as adults (or pigeons for that matter), and the result of experience was seen as an accumulation of associations varying in strength, with strength determined by the amount and recency of reinforcement/contiguity relations. In short, the theories did not confer special status to age or species differences, and thus provided a barren metaphor for those whose primary goal is to understand human growth and learning.

Computer Metaphors

Although the information-processing features of the computer metaphor have been used successfully to expand our knowledge of developmental issues in cognition, it too has serious limitations for a model of human growth. The dominant computer metaphor model that influenced the growth of psychological theory was one that concentrated on the flow of information in and between major architectural structures of the system (STM, LTM, etc.). The primary issues were when, where, and how, rather than what information is processed. Shaw and Bransford (1977) characterized the systems as "mechanistic," "purposeless," and "passive." A system that cannot grow, or show adaptive modification to a changing environment, is a strange metaphor for human thought processes which are constantly changing over the life span of the individual and the evolution of the species. Let me emphasize that this does not mean that computer systems cannot in any sense learn. Many models now exist that concentrate on acquisition mechanisms (Anzai & Simon, 1979; Anderson, Kline, & Beasley, Note 4), and many programs are now quite efficient at modeling how expert systems work (Larkin, Heller, & Greeno, 1980). But again, "modeling expert systems tells us about what an expert knows, not about how he was capable of becoming an expert" (Schank, 1980). And although one can argue that computer systems can learn, the dominant computer metaphor that has influenced the development of psychological theory is a static one (Flores & Winograd, Note 5). Further, there are surely few who would claim that artificial systems will ever be capable of the basic growth and learning mechanisms of natural man, adaptation to a natural environment (Boden, 1977).

Turvey and Shaw (Note 6) wish to differentiate natural systems from artificial ones because the types of systems differ in whether or not meaning and intentionality can be ascribed to them. Unlike the information acquired by animals as a result of interaction with a meaningful environment, the data "acquired" by a computer is not of any intrinsic interest to that computer. It is an external human agent that has interest in the data for reasons quite unspecified to the machine. It is also difficult to see how a machine can be seen as having intentionality, a dominant force in human learning.

ERIC

As meaning and intentionality arise spontaneously and are fundamental features of human thought, this difference is indeed a crucial one (Flores & Winograd, Note 5). Equally crucial for developmental psychologists is the problem of growth. Neisser (1976) claims that computer models lack one essential element, accommodation. He claims that artificial intelligence systems have not modeled cognitive development because

> The development of human intelligence occurs in a real environment with coherent properties of its own. Many of these properties vary greatly from one situation to another; others remain invariant at a deeper level. As long as programs do not represent this environment systematically, in at least some of its complexity, they cannot represent cognitive growth either. (pp. 143-144)

Thus for Neisser, as well as for ecological theorists (Shaw & Bransford, 1977; Turvey & Shaw, Note 6), the minimum unit of analysis must be the activity of an organism in its natural environmental niche.

Schema Theories

A promising direction in the growth of computer models is the incorporation of schema-like entities into their conceptualization. Minsky's (1975) frame notion, which has been favored by workers in the Artificial Intelligence field (Charniak, 1975; Winograd, 1975), and Schank's scripts and plans are basically schema notions (Schank & Abelson, 1975). One major impetus for the development of schema notions has been an attempt to deal with the question of reorganization of knowledge as a function of experience, a quintessential learning problem. These theories have been extremely successful additions to the basic information processing models and have given them a rich new metaphor with which to describe how people think. These theories also have limitations for growth models, however, that I have dealt with in detail elsewhere (Brown, 1979). Briefly, the problem is still one of accommodation.

The major scaffolding of schema theories seems to be some version of the Piagetian assimilation and accommodation interaction, or the reflection, refraction transactions of Soviet dialectic theories (Wozniak, 1975). Assimilation is the function by which the events of the world are incorporated into preexisting knowledge structures, while accommodation is the process by which the existing knowledge structures are modified in accordance with novel events. By the reciprocal influence of input on preexisting concepts and of extant knowledge on input the thinker comes to know his world. There are nontrivial problems associated with both terms, particularly concerning the problem of epistemic mediation (Shaw & Bransford, 1977; Turvey, 1978). Here we will just concentrate on the problem of growth.

A major criticism of schema theories in adult cognition is that they are basically assimilation models. Mechanisms which permit acquisition and articulation of schemata are not specified in sufficient detail to afford an adequate developmental perspective. How are existing conceptions modified in the face of inconsistent input? How do such theories deal with novelty (Höffding, 1891)? To say that "learning may be dealt with by supposing that when a radically new input is encountered a (new schema) without variables is constructed" (Rumelhart & Ortony, 1977) does not tell us either how we know it is a new input or how we construct a new schema. Similarly it is undoubtedly true that much schema growth can be accounted for by the twin processes of schema generalization and schema specification (Rumelhart & Ortony, 1977), but the theories are quite vague concerning the mechanisms and contexts which would permit such development.

An adequate theory must be able to account for growth not only with regard to gradual extension and refinement of schemata, but also with respect to major changes in perspective (Anderson, 1977) or paradigmatic shifts of theory or world view (Kuhn, 1970). It must also deal with emotionally-based resistance to such major cognitive reorganization, for it is true that inconsistencies and counterexamples are often assimilated into schemata to which a person is heavily committed, as Abelson's (1973) Cold Warrior example can illustrate. Accommodation is not the necessary result of inconsistent input. What then would constitute necessary or sufficient conditions for a schema shift, or major accommodation, to occur? How does our preexisting knowledge change as a function of experience? By gradual extension? By dynamic shifts in perspectives? Many of the interesting questions concerning schema theory are left tantalizingly unanswered.

I do not want to give the impression that developmental schema theories have answered these questions any more satisfactorily, for they too have been adept at avoiding the basic issue of growth by describing what develops rather than concentrating on how growth occurs. Indeed, just as a major

ERIC

problem with adult models is that they are generally silent on the issue of how thinking systems grow or change, so, too, a major objection to many developmental models is that at best they provide a description of the stages or states of development but cannot account for the transformations that lead to growth. There has been considerable disagreement surrounding even such basic issues as whether cognitive growth is a continuous process that proceeds slowly and gradually or whether it consists of a set of abrupt stage-like leaps (Flavell, 1971b; Toussaint, 1974; Brainerd, 1978).

Consider the pivotal developmental schema model, Piaget's theory, which rests on his changing notion of equilibration, seen by some to be a homeostatic mechanism (Riegel, 1975). The organism is constantly seeking balance and stability. Every interaction with the environment precipitates a compensating equilibration activity consisting of both an assimilative and accommodative function. The end state of these reciprocal forces is balance. A problem here is that such a homeostatic notion would serve to maintain a child at a given level of development, and one major issue has been how Piaget extracts himself from the dilemma of providing a basically homeostatic model to account for growth.

Piaget is not as insensitive to this issue as some of his critics would have us believe (Riegel, 1974), and in his more recent writings he has introduced the homeorhetic (Pufall, 1977) processes of physical and reflective abstraction (Piaget, 1970, 1971). These are not easy concepts to come to grips with and luckily, for my purposes here, it is sufficient to point out that the major questions that Piaget is attempting to answer in his more recent work focus on the problem of growth. Indeed, Riegel (1974) has characterized Piaget's own development as one of three stages, the functional, the structural, and now the transformational periods.

Thus, it would seem that even developmental theories have not yet arrived at a satisfactory conception of change and growth; as with adult theories the tendency is to fall back on an accumulation notion sometimes accompanied by reference to some unspecified qualitative reorganization at some unspecified critical stages. In defense of such theories, however, it should be said that they do address the issue; it is a constant concern; it is the focal point where theoretical controversy centers (Brown, 1979). For example, the stage vs. continuous growth controversy (Flavell, 1971a), which dominated the 1960's, centered on the problem of growth. In the 1970's, another theoretical controversy arose, between Piagetian "structuralism" and Soviet dialecticism as espoused by its American adherents (Riegel, 1975; Wozniak, 1975). This controversy was nicely illustrated by the football analogy introduced by Gardner (1973) and extended by Riegel (1974). In order to illustrate the methods of structural analysis used by Levi-Strauss to examine rituals and orgies of primitive societies, Gardner subjected American football to a similar analysis. There is structure in the field, the rules of the game, and the strategies of performance. The action is characterized by a sequence of sudden quick actions each leading to a new structural state where the action appears to be temporarily frozen. Riegel believes this analogy is suitable for capturing the essence of structural theories of growth like Piaget's early conceptions. By contrast, Riegel believes that dialectic theories, such as his own, can best be characterized by analogy to soccer, a game of ceaseless action which depends on continuous interactions between the individual members and on the transaction between the members of opposing teams. Soccer, like dialectic theory, is a game of continuous motion; football, like structural theory, is one of sudden activity producing stable states. The analogy has flaws, certainly, but it does illustrate that one of the current controversies in developmental theory, dialecticism vs. Piagetian structuralism, is rooted in the notions of growth and change. Whether or not these theoretical metaphors ever lead to a concrete increase in our understanding of human growth, they at least make us sensitive to a major problem for psychological theory.

The Missing Model: Comparative Psychology

Unlike the preceding models of psychology, comparative theories have been less influential for developmental psychologists, and as such, can perhaps be referred to as the missing model. Under this heading, comparative psychology, I mean to include a variety of disparate schools that show a fundamental concern with the biological basis of behavior and species-specific learning (e.g., ethologists, ecologists, neo-Gibsonians, animal cognition theorists, etc.). Given limited space, I have restricted myself to theories of animal learning, although I realize that I could include under this heading comparative human cognition as represented by the study of cross-cultural variability. Indeed, many of my concerns that developmental psychology should be considered a branch of comparative psychology originated from just such a consideration of comparative human cognition (for details of this argument see Cole & Means, 1980; Laboratory for Comparative Human Cognition, 1978a, 1978b). Again, given limited space, I wish to emphasize only two concepts from the comparative animal literature, compatibility and access, in order to demonstrate how a comparative approach might complement our developing picture of development.

Preparedness, Belongingness, Response Compatibility. A main theme of this approach is that significant learning is closely adapted to the species' way of life and that learning depends in very important ways on (a) the animal who is doing the learning, (b) the behavior that is required of it, and (c) the situation in which that behavior occurs. Thus, in order to understand learning, one must consider the special characteristics of the learner and the special characteristics of the environment. To introduce the terms of neo-Gibsonians such as Turvey and Shaw (Note 6), we must consider behavior in an ecosystem that consists of an animal's effectivities (goal-directed functions which reflect its potential actions), an environment (affordances), and a relationship of mutual compatibility between the two. The emphasis is not on what the animal is or what the environment is but on what the environment means to the animal. Animals are active investigatory creatures who mine the world for information on a need-to-know basis. They are constrained by their biological adaptation to their own ecological niche.

Considerable support for the species-specificity of learning has led to such concepts as belongingness or preparedness (Seligman, 1970) to explain why a certain species can learn certain activities extremely rapidly in one

ERIC

context and at the same time completely fail to learn in other contexts. For example, consider that in a "simple" aversive conditioning paradigm, how effectively a rat can be conditioned to avoid a shock depends upon the response required from the rat and critical features of the learning situation. Rats learn very quickly to run or jump to escape shock, but it is only with great difficulty that they can be trained to press a lever to escape. But aversive stimulation naturally elicits a variety of species-specific defense mechanisms (such as running away, jumping clear) which are, therefore, readily available for conditioning. Other potential responses, not related to the natural mechanism of defense (such as bar-pressing), are depressed by fear, for obvious survival reasons and are, therefore, less available for conditioning (Bolles, 1970).

These notions of belongingness, preparedness, and response compatibility bring us a long way from the type of learning that was studied during the 1930s-1940s, where rats and pigeons were set to learn arbitrary responses to arbitrary stimuli. Animals clearly come equipped to learn certain kinds of information very rapidly (Rozin, 1976); this is what is meant by the animal's effectivities (Turvey & Shaw, Note 6). But species-specific adaptation is adaptation to an environment, as can be seen even in the "simple" aversive conditioning study just described. Jumping to avoid a shock may be a "natural" response, but it is only readily conditioned if the natural environmental affordances hold. For example, if the jumping response must be made in a box with a closed lid, learning is extremely slow, if it occurs at all. If, however, the lid is off the box, and the height of the walls is commensurate with the leaping ability of the rat, one-trial learning will occur, obviously! Responding rapidly to avoid shock is readily conditioned if and only if the animal factors and environmental factors are compatible (Turvey & Shaw, Note 6).

If significant forms of animal learning are not species-independent, then perhaps it would be profitable to ask about species-dependent forms of human learning, to consider the concepts of belongingness, compatibility, or naturalness, particularly in relationship to early learning. These questions used to be of major interest to psychology, i.e., What are the prewired components that constrain early learning? What natural concepts do babies acquire readily? Are there cognitive universals of species-specific early learning? Does early learning differ in significant ways from later learning?

Earlier, I pointed out that because of our preoccupation with the 5-7 shift, we know very little about cognitive development in the preschool years. Here I would like to emphasize that a focus on early learning is called for not only because we know so little, but because many critical questions can best be addressed by considering early learning. At this point, the issue of prewired components, cross-cultural universals, natural concepts, etc. have primarily been of concern to theorists who study language acquisition (Newport, in press; Slobin, 1977; Karmiloff-Smith, Note 7), but recent work in infant learning is encouraging (Spelke, Note 8). We are now beginning to ask not: Can infants learn, remember, etc.? but: What can they learn readily? Does their biological preparedness preset them to pick up significant events in their environment (Gibson, 1979), are there universal categories of early learning? If there is a unique status to be conferred on the early acquisition of a primary language, does this tell us anything about the learning process per se (Newport, in press)? What is the status of critical period notions and early human learning? Concepts are formed for a reason; they have survival value in terms of their function or use in relation to particular cultural contexts (Cassirer, 1923; Toulmin, 1972). If this is so, we might ask what concepts young children acquire readily, and what kinds of inferences we can make from the nature of early learning about the system we are trying to understand (Gelman & Gallistel, 1978).

Although the crucial issues concerning the privileged status of early learning are largely unanswered at present; developmental psychologists have considered the compatibility issue in later learning (Inhelder, Sinclair, & Bovet, 1974). This has most often taken the form of headfitting (Jenkins, 1971; Brown, 1975, 1979) and stage-like notions (Brainerd, 1978; Flavell, 1971a; Toussaint, 1974) in theoretical arguments, and attention to the learner's "zone of potential development" (Brown & French, 1979; Vygotsky, 1978), or "region of sensitivity to instruction" (Wood & Middleton, 1975) in instructional psychology. The general concept of readiness for learning is again becoming fashionable in developmental psychology (Brown, 1975, 1979; Gelman & Gallistel, 1978; Siegler, in press).

I would also like to point out that readiness for instruction in the acquisition of scientific concepts and academic skills may not reflect

ERIC

adequately the biological preparedness of human beings for certain significant types of learning. The academic milieu is not the natural habitat for more than a few of our species and many basic scientific concepts are largely unintuitive and hence difficult to learn. When considering human potential for learning it might prove profitable to pay greater attention to so-called everyday thinking (Cole, Hood, & McDermott, Note 9).

Everyday problem-solving must be in response to a variety of environmental demands to which the learner must adjust. But we know next to nothing about demands other than those of academic settings. Both developmental and cognitive psychologists have concentrated primarily on academic intelligence, on the cognitive capabilities of the college sophomore (and children on the road to that end point). Most of our theories of adult cognition are notable for this bias. We have almost totally ignored the everyday problem-solving of the non-academic, or even of the academic members of our society for that matter. Again for basic theoretical and social policy reasons I would like to call for an increased understanding of the cognitive demands of everyday life based on a theory of cognition that includes consideration of more than academic intelligence.

Accessibility and development. The second major point I would like to borrow from comparative psychology is the concept of accessibility. For example, Rozin (1976) considers intelligence as a complex, hierarchically-organized, biological system, consisting of a repertoire of adaptive specializations that are the components or subprograms of the system.

Throughout the animal world there exist adaptive specializations related to intelligence that originate to satisfy specific problems of survival. Because they evolve as solutions to specific problems, these adaptive specializations are originally tightly wired to a narrow set of situations that called for their evolution. In lower organisms the adaptive specializations remain tightly constrained components of the system. Rozin quotes such widely known examples of prewired intelligence components as the navigational communication ability of bees that is totally restricted to the defined situation of food foraging (Von Frisch, 1967, but see also Gould, 1978 and Griffin, 1978), and the exceptionally accurate map memories of gobiid fish for their own tide pool (Aronson, 1951). This form of intelligence is tightly prewired; although it can sometimes be calibrated by environmental influence, it is pretty much preprogrammed (bird-song development is probably the most elegant illustration of the interplay between prewired components and environmental tuning; Marler, 1970). Rozin's theory is that in the course of evolution, cognitive programs become more accessible to other units of the system and can, therefore, be used flexibly in a variety of situations. This flexibility is the hallmark of higher intelligence, reaching its zenith at the level of conscious control which affords wide applicability over the full range of mental functioning.

Rozin (1976) refers to the tightly wired, limited access components in the brain as the "cognitive unconscious," and suggests that

> part of the progress in evolution toward more intelligent organisms could then be seen as gaining access to or emancipating the cognitive unconscious. Minimally, a program (adaptive specialization) could be wired into a new system or a few new systems. In the extreme, the program could be brought to the level of consciousness, which might serve the purpose of making it applicable to the full range of behaviors and problems. (pp. 256-257)

Just as part of the progress in evolution toward more intelligent organisms can be seen as gaining access to the cognitive unconscious, so too the progress of development within higher species such as man can be characterized as one of gaining access. Intelligent behavior is first tightly wired to the narrow context in which it was acquired and only later becomes extended into other domains. Thus cognitive development is the process of proceeding from the "specific inaccessible" nature of skill to the "general accessible" (Rozin, 1976).

There are two main points to Rozin's accessibility theory. First is the notion of welding (Brown, 1974, 1978; Shif, 1969), that is, intelligence components can be strictly welded to constrained domains. Skills available in one situation are not readily used in others, even though they are appropriate. Rozin uses this concept to explain the patchy nature of young children's early cognitive ability, which has been described as a composite of skills that are not necessarily covariant. Young children's programs are "not yet usable in all situations, available to consciousness or statable" (Rozin, 1976). Development is the process of gradually <u>extending</u> and connecting together the isolated skills with a possible ultimate extension into consciousness.

Closely connected is the second notion of awareness or knowledge of the system that one can use. Even if skills are widely applicable rather than tightly welded, they need not necessarily be stable, statable and conscious. Rozin would like to argue that much of formal education is the process of gaining access to the rule-based components already in the head, i.e., the process of coming to understand explicitly a system already used implicitly. As Gelman and Gallistel (1978) point out, linguistic (and possibly natural number) concepts are acquired very easily, early, and universally, but the ability to talk and the ability to access the structure of the language are not synonymous. The ability to speak does not automatically lead to an awareness of the rules of grammar governing the language.

Pylyshyn (1978) makes a similar distinction when he distinguishes between multiple access and reflective access. Multiple access to the representational components governing behavior is shown by the ability to use knowledge flexibly; i.e., a particular behavior is not delimited to a constrained set of circumstances (the welding argument). Reflective access refers to the ability to "mention as well as use" the components of the system. Developmental psychologists have also made a similar distinction between flexible use of the skills and knowledge that are available to the system and conscious, introspective knowledge concerning the availability of these skills (Brown & Campione, in press). Gardner (1978) further suggests that the hallmarks of intelligence are: (a) generative, inventive, and experimental use of knowledge rather than preprogrammed activities (multiple access), and (b) the ability to reflect upon one's own activity (reflective access). Note, however, that Gardner makes the point that no organism ever reaches a level of "total consciousness, full awareness, and constant intentionality," for these are "emergent capacities," useful as indices for comparative purposes both within and between species, but never perfectly instantiated even in the mature human. To the extent that organisms come to exhibit more and more of the qualities of reflective and multiple access, we tend to say that they exhibit intelligent behavior. Conversely, to the extent that behaviors

> (1) appear only when elicited by strong training models, (2) recur in virtually identical form over many occasions, (3) display little experimental playfulness, (4) exhibit restricted coupling to a single symbolic system, or (5) fail ever to be used to refer in 'meta' fashion to one's own activities, we are inclined to minimize their significance. (Gardner, 1978, p. 572)

I have used these notions of multiple and reflective access elsewhere as a vehicle to explain the developmental training literature and the crucial problems concerning generalization of training (Brown & Campione, in press; Brown & Chi, Note 2). Here I would like to point out that the accessing notion might give us some insights into the difference between adult and child experts. The child expert could be seen as a learner who has considerable intellectual control in one domain but can access this competence only in that domain. The rule he can apply to (for example) number conservation, he cannot apply to problems of weight or volume. Similarly the conscious control of problem solutions a child can use in one domain he cannot employ in another (this explains the "patchy" metacognitive data, for example). Again, the strategy a child can employ on a training task is one he cannot use on a novel transfer task unless given further training. Cognitive abilities are welded, or tightly wired, to specific domains of competence and therefore not readily available to other domains. Thus children are not hampered only by being universal novices, for even when they do gain expertise it tends to be strictly constrained by context.

The ideal adult expert, however, would have ready access, sometimes even conscious knowledge of his intellectual functions and should be able to apply rules and regulations widely. The adult's greater accessibility should enable him to capitalize on past expertise to guide his acquisition of new skills. Thus he can quickly adopt the interrogative and monitoring mode of the expert and marshall and modify available skills to meet the demands of the new task. In other words, the adult knows how to set about becoming an expert in new domains; he shows significant transfer from a wide variety of pertinent past experiences.

Summary

I began this section by considering the three dominant theoretical models in mainstream psychology: learning theory, computer models, and schema theories. In retrospect, we find that these theories have been less than informative models of human growth. Let me stress that the models were never intended to address issues of species-specific learning and development and, therefore, they can scarcely be held responsible for the fact that they failed to do so adequately. Let me further add that we have learned a great deal of lasting importance from these major movements in psychology. From learning theory we have found out how to engineer behavioral change in a wide variety of everyday settings. Behavior modification programs are, indeed, one of the most successful applications of psychological principles. From computer models we have learned a great deal about limited-capacity systems, selective attention, mechanisms for operating on supraspan material, executive control issues, etc. And from schema theories we have derived powerful assimilation models of top-down processing. All of these movements have profoundly influenced our current conception of the human thinker. The call for a consideration of the missing model, of comparative psychology, is a call for an added emphasis, an additional viewpoint to provide a more rounded picture, rather than an alternative model. This somewhat different perspective brings us closer to problems of human learning as adaptation to a natural environment with significant properties of its own. This perspective also makes us at least aware of the centrality of adaptation, change, and growth to theories of learning.

Induction: Preliminaries to a Theory of Learning

A recurrent theme throughout this paper has been the perennial problem of how we can characterize growth and change. I have pointed out that the prototypic theories of the acquisition of expertise and the development of

ERIC

memory offer little more than an accretion mechanism accompanied by unspecified reorganization in response to unspecified forces. As I would like to end on a positive note, I will consider here what we do know about transition mechanisms and how we might go about examining them more directly.

Basically, we are trying to understand the processes of induction, of how one goes from specific learned experiences to the formulation of a general rule that can be applied to multiple settings. This is the basic question behind access theories (Brown & Campione, in press; Rozin, 1976): How does the learner come to use knowledge flexibly? How do isolated skills become connected together, extended, and generalized? Young children learn specific rules in constrained contexts and their cognitive skills tend to be welded to the situations in which they were acquired. With repetition of many similar experiences, commonalities and differences are noted; the rule is applied appropriately and inappropriately. Inappropriate application of rules leads to conflict that induces a modification of the specific rule into a more powerful hypothesis capable of accounting for a wider range of phenomena.

Development is the process of going from the specific context-bound to the general context-free. Note, however, Gardner's (1978) warning that truly general, context-free, statable laws may be a chimera, an idealized end point; blatant failure to recognize problem isomorphs occurs in adults as well as children (Simon & Hayes, 1976; Gick & Holyoak, Note 3). Knowledge in some sense must always be context bound. But contextual binding permits of degrees; generalization and flexibility are not all-or-none phenomena but continua. It is the range of applicability of any particular process by any particular learner that forms the diagnosis of expertise or cognitive maturity. The less mature, less experienced, less intelligent suffer from a greater degree of contextual binding, but even the expert is bound by contextual constraint to some degree.

Thus, a key developmental question is how we go from strict contextual binding to a more powerful general law. One commonly suggested mechanism is conflict--conflict induces change, a notion basic to dialectic theories (Wozniak, 1975; Youniss, 1974) as well as Piagetian models (Inhelder, Sinclair, & Bovet, 1974; Smedslund, 1966). A serviceable hypothesis is maintained until a counterexample, an invidious generalization, or an incompatible outcome ensues. Conflict generated by such inconsistencies induces the formulation of a more powerful rule to account for a greater range of specific experiences--sometimes!

We cannot, as yet, specify the exact mechanisms that promote change, or even predict exactly when it will occur. But we are at the stage when it is possible to study transition mechanisms directly, and several psychologists interested in developmental issues are beginning to do so. I would advocate a three-pronged attack on the problem. The first step would be to provide as rich and detailed a description as possible of the qualitative differences between experts and novices in any task domain. Next we can begin to directly address the transition process by observing learning taking place within a single subject over time. The third step would be to attempt some form of intervention to engineer change.

The first step in the three-pronged attack is to map the developmental progression in rich detail. As we are most adept at describing developmental sequences, there is no lack of examples to illustrate this point, either from the adult expertise or developmental literatures. As an elegant developmental example, consider Siegler's (in press) rule-assessment approach. Detailed specification is given not only of the correct rule for solving a variety of scientific reasoning problems--torque, probability, time, conservation, etc.--but also of the series of increasingly more powerful partial solutions the learner entertains on his progression towards the final rule. Similarly, detailed specifications of the developmental sequence involved in the acquisition of expertise in adults are becoming increasingly common, so much so that based on such descriptions, computer models can be designed that are capable of solving, for example, pencil and paper physics problems in the mode of the expert or the novice (Larkin, Heller, & Greeno, 1980). In the case of both the child and the adult scientific thinker, the knowledge base, the exact heuristic procedures, and the encoding process can be specified in rich detail, and sensitive diagnosis of the individual's state of learning can be provided. Although the best examples of detailed developmental descriptions center on the acquisition of scientific reasoning, in principle there is no reason why comparable analyses cannot be applied to less structured domains, and such detailed descriptions are an absolute prerequisite for later stages in a research program aimed at studying change.

The second step in the three-pronged attack is to observe learning actually taking place within a subject over time. This is essentially the microgenetic approach advocated by Vygotsky (1978) and Werner (1961). The majority of developmental data is cross-sectional. The performance of groups of children, varying in age or level of expertise, is compared and contrasted. Even a great deal of longitudinal research has a surprisingly cross-sectional flavor in that we tend to see frozen shots of behavior taken at quite long intervals. Both approaches provide a picture of cognition in stasis, rather than evolving, as it were, right before one's eyes. But, again in principle, it is possible to observe learning occurring within a session, or across a few sessions, if the concept to be acquired is within the competency of the learner. A recent example of microgenetic analysis has come, perhaps surprisingly, from the adult literature. Anzai and Simon (1979) map the stages of learning that a single subject passes through as she becomes increasingly adept at solving a five-disc Tower of Hanoi problem. This strategy enables them not only to concentrate on qualitative descriptions of the stages of expertise, but also to consider transition phenomena and self-modification techniques underlying the progression from beginning to expert strategies. Anzai and Simon's learning-by-doing theory (adaptive production system) is just one example of current interest in self-modifying computer programs focused on learning processes (Anderson, Kline, & Beasley, Note 4). A similar focus on within-subject learning-by-doing in children is the strong motivation for current programs on discovery learning and zone of potential development assessments that are being developed

(Brown & French, 1979; Campione, Brown, & Ferrara, Note 10; Bransford, Stein, Shelton, & Owings, 1980).

The final step in the three-pronged attack on learning mechanisms is to attempt to engineer change via intervention. Training studies in general have been a traditional tool of the developmental psychologist and are becoming of increasing importance for both practical and applied reasons (Brown & Campione, 1978; in press; Larkin, Heller, & Greeno, 1980; Brown & Chi, Note 2). Although there are many methods of intervention, the essential element is that the experimenter provides feedback and direction. It is the experimenter who undertakes the requisite task analyses, on the basis of which he or she provides for the appropriate level of task difficulty and the correct mix of conflict trials and confirmed expectations.

Inducing change via intervention is of necessity an interactive process, one that is implicitly involved in, for example, attempts to induce more mature concepts of torque or time (Siegler, in press), and explicitly involved in, for example, mediated learning experiences (Feuerstein, 1980) and clinical testing based on Vygotsky's (1978) theory of a zone of potential development (Brown & French, 1979). The essential idea is that a child's (novice's) performance on the initial presentation of a problem is only part of the picture, and probably represents a poor estimate of his or her current cognitive capabilities. To complete the picture, we need to consider the degree of competence the child can achieve with aid. Via the intervention of a supportive, knowledgeable other (an adult, an expert, etc.), the child is led to the limits of his or her own understanding.

Mediated learning experiences, i.e., learning via the mediation of a helpful expert who provides hints, clues, counterexamples, etc., is the essence of both the Feuerstein (1980) diagnostic and training programs and the very similar programs based on Vygotsky's theory of a zone of potential development (Brown & French, 1979). In order to design either program, one must consider all stages of the three-pronged attack. First, both programs should involve detailed task analyses of the learning domain. Second, both provide an opportunity to observe learning occurring; they are essentially microgenetic approaches. And finally, in both, change is induced via the intervention of a more knowledgeable supportive other. Because of these features, these approaches to learning offer ideal ways to study induction.

Although the supportive other in the laboratory is usually the experimenter, these interactive learning experiences are intended to mimic real-life learning. Mothers (Wertsch, 1978, 1979), teachers (Schallert & Kleiman, 1979) and mastercraftsmen (Childs & Greenfield, 1980) all function as the supportive other, the agent of change responsible for structuring the child's environment in such a way that he or she will experience a judicious mix of compatible and conflicting experiences. Note also that inadequate mediated learning, either mother-child or teacher-pupil, has been implicated as a potential cause of the poor academic performance of the culturally deprived (Brown, 1977, 1978; Feuerstein, 1979). Finally, the importance of such interactive learning experiences for cognitive development, as stressed in Vygotsky's theory (1978), should not be overlooked. Vygotsky believed that all cognitive experiences are initially social but, in time, the results of such experiences become internalized. Initially the supportive other acts as the interrogator, leading the child to more powerful rules and generalizations. The interrogative, regulatory role, however, becomes internalized in the process of development, and the child becomes able to fulfill some of these functions for himself via self-regulation and self-interrogation. Mature thinkers are those who provide conflict trials for themselves, practice thought experiments, question their own basic assumptions, provide counterexamples to their own rules, etc. In short, while a great deal of thinking and learning may remain a social activity (Brown & French, 1979; Cole, Hood, & McDermott, Note 9), through the process of internalization, the mature reasoner becomes capable of providing the supportive other role for himself.

In summary, I have suggested that a three-pronged approach to the study of learning is desirable, necessary and even possible. Each step would serve a complementary function in contributing to our knowledge about learning processes. If, as a result of such an attack, we become able to (a) describe the stages of development, i.e., model developmental progressions and trajectories within a domain, (b) describe self-modification processes in individual learners acquiring expertise, and (c) engineer transition by the provision of appropriate experience, we must come to understand the essential elements of learning.

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Figure Caption

Figure 1. An organizational framework for exploring questions about learning. (Adapted from Jenkins, 1978, and Bransford, 1979)

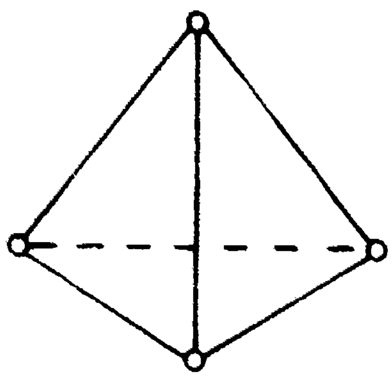
CHARACTERISTICS OF
THE LEARNER

Skills

Knowledge

Attitudes

etc.



LEARNING ACTIVITIES

Attention

Rehearsal

Elaboration

etc.

CRITERIAL TASKS

Recognition

Recall

Transfer

Problem Solving

etc.

NATURE OF THE
MATERIALS

Modality
(visual, linguistic, etc.)

Physical Structure

Psychological Structure

Conceptual Difficulty

Sequencing of Materials

etc.

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