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COGNITION AND LEARNING

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INTRODUCTION

Cognition and learning are central concepts in educational psychology. Research on these topics has been productive both for advancing fundamental scientific understanding and for informing educational practice. In this chapter, we review research accomplishments that have influenced the character of educational practice significantly. We also review research that has important practical implications but that has only begun to inform practices of education.

We believe that educational research is undergoing a major advance that will further deepen our theoretical understanding of fundamental processes of cognition, learning, and teaching and further strengthen our abilities to contribute to educational practice. This advance is leading toward a psychology of cognition and learning that includes individual, social, and environmental factors in a coherent theoretical and practical understanding. Accomplishing this change will require merging and extending concepts and methods that, until recently, have developed relatively separately in cognitive science, in ecological psychology, and in ethnographic anthropology and sociology.

The relationship between theoretical and practical understanding is one of the important aspects of our science that is currently in transition. One of the promising ideas is that research can provide more articulate and more valid principles that serve as assumptions of practice (A. L. Brown, 1994; A. L. Brown & Campione, 1994; J. S. Brown, 1991). To develop the principles of a practical theory, several groups of researchers are conducting studies that we refer to as *design experiments* (A. L. Brown, 1992; Collins, 1992). In these studies, researchers and practitioners, particularly teachers, collaborate in the design, implementation, and analysis of changes in practice. Results provide case studies that can serve as instructive models about conditions that need to be satisfied for reforms of the same kind to be successful, and about conditions that impede success. Results also contribute to an accumulating body of theoretical principles about processes of cognition and learning in the social and material environments of schools and other settings.

There are distinct traditions in educational theories and practices that derive from differing perspectives on the phenomena of the domain. We organize our discussion with three general perspectives that have developed in psychological research. We recognize that other organizing principles could be chosen, and that many of our colleagues would characterize the field in different terms. Our version groups together many research contributions that could be distinguished in important ways. We have arrived at this grouping, however, in our own effort to understand broad trends and issues in educational research, and we hope that this characterization is helpful to readers in their efforts to grasp general characteristics of the field.

The perspectives correspond to three general views of knowing and learning in European and North American thought, which, generally following Case (1991, 1992) and Packer (1985), we refer to as *empiricist, rationalist,* and *pragmatist-sociohistoric*. For the third view, Case used the simpler label "sociohistoric," but we use the admittedly more cumber-

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some term to emphasize the largely separate origins of the view in American thought. Packer's discussion, focused on the hermeneutic perspective, exemplified by Heidegger, provides background for the situative perspective (Winograd & Flores, 1986) described below. Empiricism, typified by Locke and Thorndike, emphasizes consistency of knowledge with experience. Rationalism, typified by Descartes and Piaget, emphasizes conceptual coherence and formal criteria of truth. Pragmatism, typified by Dewey and Mead, and sociohistoricism, typified by Vygotsky, emphasize that knowledge is constructed in practical activities of groups of people as they interact with each other and their material environments. Current manifestations of these three perspectives are the *behaviorist* perspective, the *cognitive* perspective, and the *situative* perspective.

All three of these perspectives have contributed, and continue to contribute, important insights to fundamental scientific knowledge and understanding of cognition and learning and have influenced educational practices significantly. While each perspective is valuable, they frame theoretical and practical issues in distinctive and complementary ways, somewhat in the way that physics, chemistry, and biology frame issues surrounding processes such as genetic replication in different but complementary ways. We hope, in this chapter, to convey the considerable strengths of all three of the perspectives and the value and importance of using their resources pluralistically in considering educational problems.

In the second section of this chapter we discuss theoretical developments within the three perspectives. The section is organized around three theoretical issues: the nature of knowing, the nature of learning and transfer, and the nature of motivation and engagement. We discuss research regarding each of these issues from the three perspectives.

In the third section we discuss ways in which the three perspectives contribute to understanding and carrying out educational practices. The section is organized around three practical issues: design of learning environments, analysis and formulation of curricula, and assessment, which we discuss from the three theoretical perspectives. We discuss these as examples of issues in educational practice in which recent and current design experiments have begun to develop a coherent body of principles in practice. Of course, these are a small subset of the practical issues that must be addressed and understood in the broad efforts to strengthen the educational system, and we discuss some additional issues briefly in the last section of this chapter (see CONCLUSIONS, p. 39).

ISSUES OF THEORETICAL CONCEPTUALIZATION

This section considers three thematic issues in the theory of cognition and learning:

- the nature of knowing,
- the nature of learning and transfer, and
- the nature of motivation and engagement.

The three general perspectives, the behaviorist/empiricist view, the cognitive/rationalist view, and the situative/pragmatist-sociohistoric view, frame each of these issues in distinctive and complementary ways.

In the behaviorist/empiricist view, knowing is an organized accumulation of associations and components of skills. Learning is the process in which associations and skills are acquired, and transfer occurs to the extent that behaviors learned in one situation are utilized in another situation. Motivation is a state of the learner that favors formation of new associations and skills, primarily involving incentives for attending to relevant aspects of the situation and for responding appropriately. There are three traditions that we consider contributed to this view. *Associationism,* which goes back to Locke and Hume, viewed knowing as the associations between ideas and learning as building new associations. *Behaviorism* took the position that knowing could be characterized only in terms of observable connections between stimuli and responses and learning in terms of forming and strengthening or weakening and extinguishing those connections through reinforcement or nonreinforcement. *Connectionism* (or neural networks) treats knowledge as the pattern of connections between neuronlike elements and learning as the strengthening or weakening of those connections.

The cognitive/rationalist perspective on knowledge emphasizes understanding of concepts and theories in different subject matter domains and general cognitive abilities, such as reasoning, planning, solving problems, and comprehending language. There are three traditions of research that we consider to be branches of the cognitive perspective. The oldest of these is *Gestalt psychology,* which emphasized the structural nature of knowledge and the importance of insight in learning. A second tradition, *constructivism,* was originally developed by Piaget and is focused on characterizing the cognitive growth of children, especially their growth in conceptual understanding. The third tradition, *symbolic information processing,* was developed in American cognitive science by Chomsky, Simon, Newell, and others and is focused on characterizing processes of language understanding, reasoning, and problem solving. (Case (1992) classified symbolic information processing as an empiricist tradition because of its focus on knowledge as a set of associative networks and procedures. We locate it in the constructivist category because of its emphasis on the organization of information in cognitive structures and procedures. This is but one example of ways in which a classification has to include relatively arbitrary boundaries. Although there are significant differences of emphasis between these research traditions, they share important framing assumptions, especially the constructivist and information-processing traditions. All three traditions emphasize the importance of organized patterns in cognitive activity. The constructivist and information-processing traditions also focus on procedures and operations for representing and reasoning about information. Learning is understood as a constructive process of conceptual growth, often involving reorganization of concepts in the learner's understanding, and growth in general cognitive abilities such as problem-solving strategies and metacognitive processes. Discussions of motivation often emphasize that much learning apparently occurs without the need for extrinsic incentives, as in the case of learning one's first language, and instead focus on ways to foster the intrinsic interest of learners in ideas and concepts.

The situative/pragmatist-sociohistoric perspective views knowledge as distributed among people and their environments, including the objects, artifacts, tools, books, and the communities of which they are a part. Analyses of activity in this perspective focus on processes of interaction of individuals with other people and with physical and technological systems. Indeed, the term *interactive* (Bickhard & Richie, 1983) is a close synonym for the term *situative*. Several research traditions have contributed to the situative perspective. The best established of these is *ethnography*, including the study of cultural practices and patterns of social interactions, as well as discourse analysis and conversation analysis in activity theory, sociolinguistics, anthropology, and sociology. Another research tradition is *ecological psychology*, which studies behaviors as physical interactions in which animals, including people, participate in physical and technological systems (e.g., Turvey, 1990, 1992). A third research tradition is *situation theory*, in logic and the philosophy of mind and language, which analyzes meaning and action as relational systems and is developing a reformulation of logic to support these relational analyses (e.g., Barwise & Perry, 1983; Devlin, 1991). Knowing, in this perspective, is both an attribute of groups that carry out cooperative activities and an attribute of individuals who participate in the communities of which they are members. A group or individual with knowledge is attuned to the regularities of activities, which include the constraints and affordances of social practices and of the material and technological systems of environments. Learning by a group or individual involves becoming attuned to constraints and affordances of material and social systems with which they interact. Discussions of motivation in this perspective often emphasize engagement of individuals with the functions and goals of the community, including interpersonal commitments and ways in which individuals' identities are enhanced or diminished by their participation.

Views of Knowing

The main reason for schooling is that students should increase in what they know. But what is knowing? A major outcome of research in educational psychology is the development of theories, grounded in empirical evidence, that help us understand what knowing is, as well as how it develops in students' learning activities. Different beliefs about the nature of knowing underlie different priorities, values, technologies, and practices in educational activity.

Knowing as Having Associations: The Behaviorist/Empiricist View. A strong tradition in psychology seeks to characterize knowing as having an organized collection of connections among elementary mental or behavioral units. These units may be elementary sensory impressions that combine to form percepts and concepts, or stimulus-response associations, or abstract elements of parallel, distributed networks. This empiricist view emphasizes that what someone knows is often a reflection of that person's experience, and indeed, that coming to know something requires an experience in which that knowledge can be acquired.

Stimulus-Response Association Theory. A thoroughly developed version of the behaviorist view was accomplished beginning in the 1930s. Key figures in this development were Tolman (1932), Guthrie (1935), Skinner (1938), and Hull (1943), and the theoretical issues continue to be developed in current research (e.g., Rescorla & Wagner, 1972). All of these theories are framed by the assumption that behavior is to be understood as the responses of an organism to stimuli in the situation, and they make varying assumptions about the processes by which stimulus-response associations are strengthened and weakened in the events of an organism's activity and experience. Although most of the systematic theoretical development is based on the results of experiments on learning by animals, especially rats and pigeons, the theoretical ideas of stimulus-response associations were also developed in analyses of human learning, especially those involving rote memorization (e.g., Estes, 1959; Underwood & Schulz, 1960). A major influence of stimulus-response theory in education has been its support of a view of knowledge as an assembly of specific responses, a form of knowledge often expressed as detailed *behavioral objectives* in curricula and assessment.

An important general technique of *task analysis* has been built on the assumption of associative knowing. Associationist theories of learning called for analysis of school subjects into collections of stimulus-response connections (e.g., Thorndike, 1931). Under the influence of behaviorists such as Skinner (1958), a further proposal that the collections of specific associations be expressed as *behavioral objectives* was added, and Gagné (1965) developed an elaborate system of carrying out analyses of school tasks into discriminations, classifications, and response sequences. This approach has had an enormous influence on the design of curricula, where learning tasks are arranged in sequences based on their relative complexity according to a task analysis, with simpler components treated as prerequisites for more complex tasks in which the analysis indicates that the prerequisites are included as components (e.g., Gagné, 1968).

Parallel-Distributed Connectionism. The *parallel-distributed network* or *neural network* approach characterizes knowing in terms of patterns of activation of units that excite or inhibit each other (cf. Rumelhart, McClelland, & PDP Research Group, 1986). These networks differ from networks of associations in traditional behavior theory, which have units of stimuli and responses. They also differ from the structures and procedures of cognitive theory, which have units that receive and transmit symbols. In parallel-distributed connectionism, cognitive states are represented as patterns of activation in a network of elementary units. Each unit has only a level of activation and connections with other units that transmit either excitation or inhibition. In recognizing a pattern in the situation, the network settles into a characteristic pattern of active and inactive nodes that is relatively stable, and that is different from the activation pattern into which it settles under different stimulus conditions. In acting in the situation, a pattern of activation occurs that results in a specific pattern of movement. Different patterns that can be perceived, and different actions that can be performed, correspond to different patterns of activation involving the same units, rather than to different units.

Although connectionist theories have not yet been applied extensively to educational questions, the approach is potentially very significant. It suggests an analysis of knowledge in terms of attunement to regularities in the patterns of environmental events and activities rather than in terms of components, as in behavioristic task analyses.

Knowing as Concepts and Cognitive Abilities: The Cognitive/Rationalist View. A second view treats knowing as having structures of information and processes that recognize and construct patterns of symbols in order to understand concepts and to exhibit general abilities, such as reasoning, solving problems, and using and understanding language. This approach provides a basis for analyzing concepts and procedures of subject matter curricula in terms of information structures that have been specified in considerable detail. This has provided much stronger contact between cognitively oriented educational psychologists and educators concerned with the curricula and teaching of subject matter domains than there was with behavioristic educational psychologists.

Conceptual growth and the growth of reasoning have long been active research topics in developmental psychology, and these studies have provided characterizations of general abilities and understandings that change as children grow older. Information-processing theories have also provided ways to look at general cognitive abilities as general strategies for handling information and as metacognitive processes.

General Schemata for Understanding and Reasoning. Piaget's extensive body of work on children's cognitive development was constructed over several decades, but became influential in American educational psychology in the 1960s. His early work (e.g., 1927/1972, 1929, 1932) had focused on the specific knowledge structures that children develop—knowledge about physical and social causality, about the origins of rules, laws, and moral obligation, about how machines work. Beginning in the 1940s, however, Piaget began to formulate a theory of the development of logical structures and, although he actively rejected notions of biological determinism in human development, he argued that the capacity to comprehend certain concepts was limited by the child's level of general *logicodeductive* development. Piaget's influence on educational practice has been considerable, especially in reinforcing and informing efforts to organize science learning in a way that involves students' discovery of principles and concepts.

Conceptual Understanding. Research on children's understanding of general concepts continues to be a significant topic in developmental psychology. Recent research has focused on the growth of children's understanding in domains such as concepts of number (e.g., Gelman & Gallistel, 1978; L. B. Resnick, 1989), biological concepts about living and nonliving things (e.g., Carey, 1985; Hatano & Inagaki, 1987; Keil, 1989), and psychological concepts about mental functioning (e.g., J. Flavell, Green, & Flavell, 1986; Wellman, 1990). This research is developing accounts of the rich intuitive conceptual understanding that children have, and that undergoes significant change as they grow older. The research emphasizes that children's learning must be viewed as transforming significant understanding that they already have, rather than as simple acquisitions written on blank slates. The results suggest that children's understanding in the domain of concepts of a subject matter provides a more important guide for the organization of curricula and teaching than does the stage they have reached in developing their general operational abilities in reasoning. There is considerable evidence that as children grow, they are able to handle more complicated tasks (Case, 1985), but we doubt that educational practice needs to be guided very strongly by ideas about the development of general schemata of logicodeductive operations in children's reasoning.

Another line of research has examined conceptual understanding where people display conceptual misunderstandings that deviate from accepted scientific concepts. These alternative understandings have been characterized by some as "misconceptions" (e.g., McCloskey, 1983), and educators have been concerned to find ways to combat them. More recent analyses have characterized the results in terms of students' use of intuitive conceptions that need to be further refined to apply correctly in the situations that evoke misconceptions (e.g., Chi, Slotta, & de Leeuw, 1994; J. P. Smith, diSessa, & Roschelle, 1993/1994; see also chapter 15, this volume). This view suggests that intuitive understanding provides the basis for new understandings that develop and should be treated as an essential resource in students' learning.

Reading and Writing. A major achievement of the information-processing approach to cognition has been the analysis of language abilities such as reading and writing. Reading has been analyzed as a combination of abilities to encode information from text into mental representations of letters and words, to recognize the words and activate representations of their meanings, to combine representations of words into the patterns of phrases and sentences and to form representations of propositions that they express, and to combine representations of propositions into coherent representations of information conveyed by texts (e.g., Just & Carpenter, 1980; Kintsch & van Dijk, 1978; A. M. Lesgold & Perfetti, 1978). The importance in these models of recognizing and representing relations among the components of a text has led to revised measures of text readability (Miller & Kintsch, 1980) and methods of systematically improving texts so they are easier to understand (Britten & Gülgöz, 1991; Chambliss & Calfee, 1996; Kintsch, 1994).

Problem Solving and Reasoning. The cognitive theory developed in the 1970s and 1980s included information-processing models of problem solving and reasoning. Using concepts and programming methods from the theory of text comprehension (e.g., Kintsch & van Dijk, 1978) and problem solving (Newell & Simon, 1972), several analyses of understanding and solving text problems, especially in mathematics and science, have been developed (see Greeno & Simon, 1989; VanLehn, 1989, for reviews). The most popular programming format has been the production system, where each component of knowledge is represented as a condition–action pair in which the condition is a pattern of symbols and the action is another pattern of symbols that is constructed by the program if the pattern in the condition is matched in the situation. These models include simulations of text comprehension that construct representations of the given information of the problem using schemata for general patterns. Based on the question of the problem, a model simulates setting a goal to find that answer, and applies operators that transform information in the problem representation, setting subgoals if necessary, to construct a solution of the problem.

Researchers have also investigated reasoning and understanding that depends on mental representations, called *mental models,* that provide a kind of simulation of events rather than descriptions of events (Gentner & Stevens, 1983; Halford, 1993; Johnson-Laird, 1983). In reasoning with a descriptive representation, as Newell & Simon (1972) hypothesized, an operation is applied to an expression, such as an equation or a proposition, that describes a situation. The operation produces a new expression describing the situation. In reasoning with a mental simulation, a model represents properties of the system, and operating on the model changes some of those properties in ways that correspond to changes in properties of the system.

General and Specific Strategies and Competencies. The idea of general problem-solving heuristics has also played an important role in the cognitive view of knowing and learning. Newell (1980) introduced the terms *weak methods* and *strong methods* as labels for the distinction between general skills and methods in specific domains. By *strong*, Newell meant that a person with a great deal of relevant, well-organized knowledge would be able to solve a new problem efficiently, in part by recognizing familiar patterns in the new situation, thus bypassing the need for tedious, step-by-step analysis. But strong methods require domain-specific knowledge, and everyone is likely to encounter problems for which they do not have the appropriate domain-specific knowledge. In those cases, they must rely on more general but weaker (more time-consuming, less reliable) general heuristics.

A specific theoretical version of weak problem-solving methods was expressed in the General Problem Solver (GPS), developed as a contribution to both artificial intelligence (Ernst & Newell, 1969) and cognitive psychology (Newell & Simon, 1972). The problem-solving method ("means–ends analysis") programmed in GPS is a general heuristic procedure that has to be combined with information in a specific domain to work on a problem.

General competencies for thinking have been studied and discussed extensively in developmental psychology (see our earlier discussion of Piaget), in the development of curricula for development of thinking skills (in part III), and in the psychology of individual differences (see chapters 8 and 9). In differential psychology, there is a long-standing debate over whether there is a significant factor of general intelligence (e.g., Spearman, 1904), or whether differences among individuals consist of multiple competencies in domains such as verbal, spatial, mechanical, and the use of formal symbols (Thurstone, 1938). The latter view has been developed in recent research and discussion by H. Gardner (1983).

Many writers concerned with learning in specific subjects have also emphasized the need for students to adopt general patterns of thinking and problem solving that are productive in those domains. A well-known example in mathematics is the work of Polya (e.g., 1945) who characterized heuristic methods for solving difficult problems in ways that can lead to enrichment of understanding. Schoenfeld (1985) has extended this line of thinking with systematic research on mathematical problem solving.

Recognition of the power of strong, knowledge-specific methods in problem solving was part of what has been called the *knowledge revolution* within cognitive science (Feigenbaum, 1989). Cognitive research began to focus heavily on mapping the nature of the knowledge that supports strong problem solving and reasoning. In educational psychology, study after study showed that students' ability to understand texts, to solve mathematical problems, or to learn new concepts in the social or natural sciences depended heavily on what the students already knew (Glaser, 1984). People need organizing schemata in order to understand and use new information. The richer and more appropriate to the problem these schemata are, the faster and more effectively will people be able to solve the problem. We discuss research concerning general strategic aspects of knowing and the contents of subject matter domains further in the third section of this chapter, ISSUES OF PRACTICAL CONCEPTUALIZATION, p. 26.

Metacognitive Processes. Another important theme in the cognitive view of knowing is the concept of *metacognition,* the capacity to reflect upon one's own thinking, and thereby to monitor and manage it. These strategies have been studied under many labels, all pointing to the importance of self-conscious management of one's own learning and thinking processes.

This theme was introduced by developmental psychologists (e.g., A. L. Brown, 1978; Flavell & Wellman, 1977), who noted that a reflective, self-monitoring capacity discriminated developmentally advanced children from their less advanced peers. For example, research with children who have special difficulty in reading has shown that they differ particularly from more able readers in being less likely to monitor their comprehension and actively generate expectations about the information in the passage (A. L. Brown & Campione, 1981).

Research comparing excellent adult learners with less capable ones also confirmed that the most successful learners elaborate what they read and construct explanations for themselves. Chi, Bassok, Lewis, Riemann, and Glaser (1989) provided a particularly clear demonstration in a study of physics students learning from worked-out example problems. Students were classified on the basis of their performance on a test given after they studied a chapter in a physics text, and of their activities during learning as they studied the example problems. The better students treated the examples quite differently, constructing explanations of solutions in terms of problem goals and physics principles discussed in the texts, rather than simply attending to the sequence of steps in solutions, as the poorer students tended to do. An assumption that learning is facilitated when students construct explanations of problem solutions is also supported by evidence provided by C. Lewis (1988), and is used in the tutoring systems that Anderson and his associates have developed for domains of high school geometry and algebra and LISP programming (Anderson, Boyle, & Reiser, 1985). A contrast like the one between Chi and colleagues' (1989) better and poorer students was also discussed by Marton, Hounsell, and Entwhistle (1984), who distinguished between deep and shallow strategic approaches to learning taken by different students.

Students' Epistemological Beliefs. Students' learning activities are also influenced by their beliefs and understandings of the nature of knowing and learning. An example was observed by diSessa (1985), who contrasted the learning activities of two students in a college physics course. One student, who called himself a "results man," focused on acquiring the ability to solve problems correctly. The other student focused on understanding concepts and principles and their interrelations. DiSessa characterized these two students as having different naive epistemologies, that is, as basing their learning on different beliefs and understandings of what it means to know in the domain of physics. According to the "results man," knowing was constituted by the ability to solve problems correctly, but according to the other student, knowing involved conceptual understanding.

Dweck (1983; Dweck & Legett, 1988) studied how differences in students' epistemological beliefs and understandings interact with their engagement in tasks that involve difficult challenges and their persistence in the face of difficulties. She differentiated students as to whether they pursue performance goals (i.e., they want to do well) or learning goals (i.e., they want to become more capable). Those students who believe that intelligence is a fixed trait (you are either smart or not in some area) tend to adopt performance goals, while those who believe that intelligence is acquired tend to adopt learning goals. If students pursue learning goals, they seek challenges and show high persistence in the face of difficulties. But if they adopt performance goals, they will only seek challenges and persist when they are confident of their ability to accomplish the task. Surprisingly, adoption of performance versus learning goals does not correlate with intelligence. In fact, Dweck found that highly intelligent girls tend to adopt performance goals, whereas highly intelligent boys are more likely to adopt learning goals.

Research by Gilligan and her associates (e.g., Gilligan, Ward, Taylor, & Bardige, 1988) has shown that the experiences of many girls during adolescence have particularly debilitating effects on their beliefs and understandings of themselves as knowing agents. They attribute these effects to broad social influences, including strong social expectations that girls should not participate assertively in intellectual activities, at the risk of being perceived as unfeminine.

An extensive discussion of epistemological beliefs was provided by Belenky, Clinchy, Goldberger, and Tarule (1986), on the basis of interviews with women about their beliefs and understandings of their experiences and capabilities for learning. Belenky et al. distinguished several epistemological stances, including a belief that knowledge is received from authorities, and two varieties of constructivism, one in which knowledge is distinct from what is known, and one in which knowledge is a form of connection with the ideas, information, and people that one knows about.

Knowing as Distributed in the World: The Situative/Pragmatist-Sociohistoric View. A third perspective on knowing focuses on the way knowledge is distributed in the world among individuals, the tools, artifacts, and books that they use, and the communities and practices in which they participate. The situative view of knowing, involving attunements to constraints and affordances of activity systems, suggests a fundamental change in the way that instructional tasks are analyzed. The change is away from analyses of component subtasks to analyses of the regularities of successful activity.

Participation in Practices of Communities. One form of knowing, from this point of view, is an attribute of groups that carry out cooperative activities. Groups are composed of individuals, of course, and considering knowing as abilities of groups in their practices (i.e., *collective knowing*) is complementary to considering knowing of individuals as their abilities to participate in those practices (i.e., *individual knowing*). The practices of a community provide facilitating and inhibiting patterns that organize the group's activities and the participation of individuals who are attuned to those regularities.

Cognitive research has begun to move out of the laboratory and toward a concern with more naturalistic learning environments. This research carries forward many elements of older traditions of human factors research, but it is much broader in scope and orientation, including ethnographic, ethnomethodological, and cultural psychology traditions. A theory of cognitive situations is beginning to emerge that takes the distributed nature of cognition as a starting point (J. S. Brown, Collins, & Duguid, 1989; L. B. Resnick, 1987b). In these theories, success in cognitive functions such as reasoning, remembering, and perceiving is understood as an achievement of a system, with contributions of the individuals who participate, along with tools and artifacts. This means that thinking is situated in a particular context of intentions, social partners, and tools (L. B. Resnick, Levine, & Teasley, 1991; J. M. Levine, Resnick, & Higgins, 1993).

The knowing of communities in their social practices has traditionally been studied more by anthropologists and sociologists than by psychologists (although see Cole, Gay, Glick, & Sharp, 1971), and recent analyses of cognitive performance in work settings continue that tradition (e.g., Hutchins, 1995; Workplace Project, 1991). Processes of discourse in social interaction have been studied for some time by sociolinguists and ethnomethodologists (e.g., Gumperz, 1982; Schegloff, 1991) and, more recently, by psycholinguists (e.g., Clark, 1992).

Everyday practices involving reasoning about quantities have been studied extensively, providing important information about reasoning capabilities that are not acquired in school (Lave, 1988; Nunes, Schliemann, & Carraher, 1993; Saxe, 1990). Practices of research communities have also been studied, for example, by Latour and Woolgar (1979/1986), Lynch (1993), and Ochs, Jacoby, and Gonzalez (1994). These studies have provided information about ways in which information is interpreted and portrayed in the construction of data and explanations in the literature of a field such as physics and biology.

Knowing how to participate in social practices plays a crucial role in all aspects of a student's learning in and out of school. Classroom activities are organized in various ways, and children participate in them more or less successfully. In typical patterns of classroom discourse described by Cazden (1986), Mehan (1979), and others, the teacher addresses questions to the class, receives an answer from someone he or she calls on, and evaluates the answer for the class's *information*. Different patterns of discourse in which small groups of students interact with each other (e.g., Cohen, 1986) or in which students in the class formulate questions and evaluate other students' presentations are possible and have been discussed (e.g., Cobb et al., 1991; Fawcett, 1938; Lampert, 1990; Schoenfeld, 1987). A major feature of these alternative patterns of discourse is the distribution of responsibility for proposing questions and explanations and for evaluating contributions made by students, with more of those functions in the hands of students than in traditional didactic instruction. Knowing how to participate in these discourse practices is an important aspect of ability to understand and inquire in subject matter disciplines, which includes ability to distinguish questions, arguments, and explanations that are taken as valid in the disciplines.

Abilities to Interact with Physical Environments. Ecological psychology also redefines the nature of knowing, but the analysis focuses on relations between actions and the physical situation. Historically, a few psychologists have objected to the stimulus-response view of behavior, arguing that a more general, interactionist view of the relation between action and situations is appropriate (e.g., Dewey, 1896; Lashley, 1951). However, this interactionist view was not developed systematically until Gibson (1966) developed a theory of direct perception. Gibson focused on perception in the context of orienting and moving about in an environment and argued that perception should be understood as a process of picking up information as an aspect of the agent's activity, rather than as a process of constructing representations of the situation and operating on those representations. Gibson (1979/1986) also began to develop the concept of *affordances*, arguing that the psychologically significant information in environments specifies ways in which spatial settings and objects can contribute to our interactions with them. Recently, Turvey (1990, 1992) and others have been developing this interactionist view by working out specific analyses of activities, such as juggling, in which an agent and some physical objects interact, applying forces to each other and moving through space in a coordinated system. Norman (1988) has discussed principles in the design of artifacts that provide affordances—sometimes of a negative kind—for human interactions with them.

Views of Learning and Transfer

Learning and transfer are critical issues for educational psychology. Learning is the process by which knowledge is increased or modified. Transfer is the process of applying knowledge in new situations. Educators want the knowledge that is acquired in school to apply generally in students' lives, rather than being limited to the situations of classrooms where it is acquired. That is to say, they want the knowledge to transfer. In this section, we summarize some of the contributions of psychological research to the understanding of learning and transfer and consider ways in which these contributions have been influenced by the views of knowing that we discussed in the previous section.

Acquiring and Applying Associations: The Behaviorist/Empiricist View

Learning. When people's knowledge is viewed as their having associations between ideas or stimuli and responses, learning is the formation, strengthening, and adjustment of those associations. Processes that have been analyzed in research include (a) conditioning of reflexes, where a response to one situation comes to be associated with another situation; (b) reinforcement of stimulus-response associations, where particular connections are strengthened by feedback from the environment; and (c) forming associations among units of verbal items, as when people learn lists of words or digits.

The research on basic associative processes of learning has important implications for teaching and learning. One is the importance of individual students' having opportunities to give responses of the kind that they are to learn and of feedback that is contingent on the individual student's responses. For learning routine tasks, there are significant advantages of efficiency in individualizing instruction, so that each student responds actively to questions and problems and receives feedback for each response, feedback that the student can relate clearly to the response that he or she gave. This has informed the development of programmed instruction and computer programs that teach routine skills in mathematics, reading, and vocabulary. It has been found that students learn more effectively from such individualized instruction than from standard classroom instruction (e.g., Galanter, 1968; Suppes & Morningstar, 1972).

Researchers in behavioral conditioning also found that effective learning usually requires significant preparation, or *shaping*, in which the learner becomes oriented to the general conditions of activity in which learning will occur. This is especially important in *instrumental conditioning*, where the effect of instruction depends on being able to reinforce desired responses, which therefore must occur in order for the reinforcements to be provided. In conditioning experiments with animals, shaping involves a period in which the trainer attends carefully to the animal's activity in the learning environment, first providing reinforcement for being near the apparatus that the animal can respond to (e.g., a disk that a pigeon can peck), then for orienting toward the apparatus, then for touching it, and finally only for pecking it, the response that is desired. This kind of instruction-by-approximation has clear parallels in school learning, where skilled teachers attend to students' progress and provide encouragement for students' attention and efforts as they achieve better approximations to the patterns of behavior that they need in order to succeed.

Analysis of complex tasks into learning hierarchies (Gagné, 1968) has been used in designing instructional sequences and computer-based systems for learning routine skills. The hypothesis that smaller units of behavior need to be mastered as prerequisites for more complex units provides a basis for arranging sequences of instruction in which students are able to succeed by learning in small steps. This *decomposition hypothesis* is currently being questioned by many in the cognitive community (e.g., Resnick & Resnick, 1991), based on a concern that instruction limited to presentation of small-to-large components can result in mechanical knowledge without sufficient development of the usefulness or conceptual basis for procedures that are learned.

The phenomena of classical conditioning emphasize that important learning can occur that is unintended, called *incidental learning*. This is especially important regarding affective responses: Students' experiences of either pleasure and satisfaction or embarrassment and humiliation are likely to become conditioned to stimuli in the circumstances of their learning, thereby shaping students' future affective responses to the situations of school learning.

In the connectionist perspective, learning is viewed as developing a pattern of activity that is aligned better with the regularities of the environment and successful performance, rather than as additions of components to the learner's cognitive structure. Strengths of excitatory and inhibitory connections in the network are changed by presentation of feedback that allows the pattern of activation in the network to be compared with a desired pattern, and changes occur through a process of adjusting connections to increase the match between the actual pattern of activation and the desired pattern (e.g., Rumelhart, Hinton, & Williams, 1986).

Transfer. In the view that knowing is having associations, learning in a new situation depends on how many, and which kinds of associations needed in the new situation have already been acquired in the previous situation. The idea of transfer in conditioning involves *gradients* of similarity along stimulus dimensions, so that a response learned as an association to one stimulus generalizes more strongly to other stimuli that are similar to it in all respects, and less strongly to stimuli that differ from it in one or more dimensions. Thorndike (1903) expressed this as a theory of transfer based on common elements. Later theories expressed parallel ideas, involving similarity between stimuli and responses (Osgood, 1949), and the numbers and kinds of condition–action production rules that are shared between procedures that are learned initially and procedures that are learned in a transfer situation (Singley & Anderson, 1989).

Acquiring and Using Conceptual and Cognitive Structures: The Cognitive/Rationalist View

Conceptual Learning. Most recent research on students' conceptual learning in subject matter domains has been organized by the framing assumption of *constructivism,* the assumption that understanding is gained by an active process of construction rather than by passive assimilation of information or rote memorization (Confrey, 1990). Constructivist research in the fields of subject matter teaching and learning has been strongly influenced by Piaget's ideas about cognitive development, particularly by the idea that conceptual abilities grow out of intellectual activity rather than by absorption of information (e.g., Steffe, Cobb, & von Glasersfeld, 1988).

Educational psychologists have contributed empirical and theoretical research to this constructivist program. Many of these studies have focused on use of concrete materials and other analogies that are manipulated in ways that illustrate conceptual principles (e.g., D. E. Brown & Clement, 1989; Brownell, 1935; L. B. Resnick & Omanson, 1987; Sayeki, Ueno, & Nagasaka, 1991; Wertheimer, 1945/1959). Several recent studies have shown ways in which conceptual understanding can be fostered in interactive computer environments (Kaput, 1989; Moore, 1993; Pea, 1993; Roschelle, 1992; Schwarz, Kohn, & Resnick, 1994; B. Y. White, 1993; Wiser & Kipman, 1988). These studies provide valuable information about conditions in which learning with understanding can occur.

Studies of cognitive development in subject matter domains also have contributed to the constructivist program. They show how significant conceptual growth in children's informal understanding of numerical, biological, and psychological concepts occurs over a period of years.

Another line of research emphasizes addressing students' initial conceptual understandings by having them participate in conversations about the meanings of concepts, including formulating and evaluating questions, hypotheses, and arguments (Lampert, 1990; Minstrell, 1989; Yackel, Cobb, & Wood, 1991). The role of this discourse depends on the kind of knowledge that students have, and there are differing hypotheses about that, as we discussed in the previous section on p. 18. If one believes that students have an incorrect scientific theory or *misconception* in the domain, then it is appropriate to elicit their beliefs and confront them with contradictory evidence. On the other hand, if one believes that their understanding is based on intuitions that are valid in some circumstances, then a more exploratory kind of conversation is probably more effective. Then students can develop ways of talking and thinking about phenomena and gradually become more attuned to the ways in which properties in the domain are related (J. P. Smith, diSessa, & Roschelle, 1993/1994; B. White & Frederiksen, 1990).

Learning Problem-Solving Representations and Procedures. Symbolic information-processing models of solving text problems characterize knowledge for solving problems in terms of procedures that represent problem information, set goals, and transform symbolic expressions to satisfy the main problem goal. Models of learning in this tradition simulate processes that add to and modify the learners' procedural knowledge (see VanLehn, 1989, for a review).

One example, the Soar program, developed by Newell (1990) and his associates, constructs new procedural knowledge using a combination of weak problem-solving methods (see p. 18) and a process of chunking that converts a trace of successful problem solving into new procedures. Soar works on a problem using whatever representations and procedures it already has. When it reaches an impasse that involves a subgoal for which it does not have adequate procedures, it constructs a problem space in which to find a solution to that subproblem using weak search methods. When it has found a way to achieve that subgoal it constructs a new procedure by a process of chunking.

Another example, by Anderson (1983), simulates three kinds of learning processes: proceduralization, tuning, and automization. Anderson assumed that in an early stage of learning to solve a kind of problem, the student interprets information that is available in declarative form, such as written or spoken instructions or worked example problems. One hypothesis of the model is that procedural knowledge is constructed, in the form of condition–action production rules, that associate actions that are performed in interpreting the declarative information with goals and stimulus information that the student attends to. The conditions of production rules that are constructed are consistent with information in the specific situation in which they are formed, but those rules rarely have conditions that include just the features that are needed to provide correct performance. As learning proceeds, tuning of the production rules occurs in processes of discrimination and generalization, based on feedback that the student's responses are correct or in error. Finally, the model's procedures become more efficient by combining rules that occur together.

Some information-processing models of learning include hypotheses about roles of conceptual understanding in learning problem-solving procedures. One model, by VanLehn, Jones, and Chi (1992), simulates learning to solve physics text problems. Based on the finding of Chi et al. (1989) that better learners constructed explanations of problem steps in terms of problem goals and physics concepts, VanLehn et al. simulated the construction of explanations as a process of deriving the steps of solved examples and thereby adding problem-solving rules that are associated with relevant conditions of problems. The model also simulates learning of derivational knowledge by storing representations of its derivations in a form that allows their use as analogues to control search in later problem solving. Because of this latter feature, the model learns more effectively during its own problem solving, in addition to acquiring more useful rules while it studies examples.

Another example is in work by Ohlsson and Rees (1991), whose model hypothesizes knowledge of general principles in the form of constraints that are applied by the learning program or by a tutor to evaluate the results of applying the model's procedural knowledge as it works on problems. When a step in problem solving produces violation of a constraint, the model constructs new rules that take account of the conditions specified in the constraint.

Transfer. Concepts and principles of a domain are designed to provide generality, and studies of learning and transfer in domains have often used tasks involving transfer to test whether students achieved understanding. In the cognitive perspective, transfer is assumed to depend on acquiring an abstract mental representation in the form of a schema that designates relations that compose a structure that is invariant across situations. In analyses of problem solving, there is evidence that the general schema has to be acquired in initial learning (Bassok & Holyoak, 1989; Gick & Holyoak, 1983), along with practice in applying the schema to examples (Holland, Holyoak, Nisbett, & Thagard, 1986), and that schemata that can be induced naturally as patterns of everyday experience are more easily taught than formal, syntactic rule systems (Nisbett, Fong, Lehman, & Cheng, 1987).

A large body of research has found that students often fail to transfer from learning that they have accomplished. A. L. Brown (1989) pointed out that in research about children's ability to transfer, the deck is stacked in favor of finding that transfer does not occur. Children are asked to solve a problem, then a new problem is presented, and the experimenter observes whether the new problem is solved in a way that uses the initial solution. Usually, experimenters do their best to hide the relation between the two problems when the second problem is presented, so that if children do transfer, we can be sure they did so spontaneously. More important, for Brown, the potential generality of the initial solution is not made clear. When Brown and Kane (1988) taught solutions of problems and asked children to explain why the solutions were examples of general themes, thus calling attention to their potential generality, the children in their experiments transferred much more successfully. (See also chapter 3.)

There is an important theoretical and educational principle in these results about transfer. The manner in which solutions of problems are presented can make a major difference for the generality of what is learned. If students understand the solution as an example of a general method, and if they understand the general features of the learning situation that are relevant to use of the method, the abilities they learn are more likely to be applied generally. This idea is consistent with results of research that has studied educational programs that are designed to strengthen students' general strategies and schemata for thinking and reasoning. Two general conclusions of this research are (a) that productive learning of thinking practices occurs mainly in settings where subject matter content is involved, and (b) successful programs emphasize the social processes of explanation, formulation of problems and questions, and argumentation (L. B. Resnick, 1987a).

Becoming Attuned to Constraints and Affordances Through Participation: The Situative/Pragmatist-Sociohistoric View

Learning. When knowing is viewed as practices of communities and the abilities of individuals to participate in those practices, then learning is the strengthening of those practices and participatory abilities. Systems in which individuals learn to participate in social practices are very common and include apprenticeship and other forms of being initiated into the practices of a group. Lave and Wenger (1991) reviewed several studies of learning involving apprenticeship and concluded that a crucial factor in the success of such a system is that learners must be afforded legitimate peripheral participation, which involves access to the practices that they are expected to learn and genuine participation in the activities and concerns of the group. Lave and Wenger characterized learning of practices as processes of participation in which beginners are relatively peripheral in the activities of a community, and as they become more experienced and adept, their participation becomes more central. A crucial issue in the nature of learning is whether, and in what ways, the peripheral participation of beginners is legitimate. For an environment of apprenticeship to be a productive environment of learning, learners need to have opportunities to observe and practice activities in which their abilities will become stronger in ways that correspond to progress toward more central participation.

The view that learning of practices occurs through participation is at the root of the practices of apprenticeship, which occur in work environments where apprentices are guided and supervised by masters. In successful apprenticeship learning, masters teach by showing apprentices how to do a task (modeling), and then helping them as they try to do it on their own (coaching and fading). Lave and Wenger (1991) emphasized how an apprentice's identity derives from becoming part of the community of workers. They also noted that an apprenticeship relationship can be unproductive for learning. Productive apprenticeship depends on opportunities for the apprentice to participate legitimately, albeit peripherally, in the activities that he or she is learning. The motive for becoming a more central participant in a community of practice can provide a powerful motivation for learning. Of course, what is learned in apprenticeship may not easily generalize to other contexts. Collins, Brown, and Newman (1989) attempted to characterize how the modeling, coaching, and fading paradigm of apprenticeship might be applied to learning the cognitive subjects of school in an approach they called "cognitive apprenticeship."

Stein, Silver, and Smith (in press) have analyzed aspects of middle school mathematics teachers modifying their practices to involve students in more active meaning making and student-to-student communication from the perspective of their participation in a community of teachers working with shared goals for reform. Hutchins (1993) has given an account of how seamen learn the practices of navigating a large ship. The account includes discussion of an arrangement of tasks that the novice proceeds through in becoming competent and the importance of interaction with other, more experienced seamen in the situations in which the learning occurs.

A major goal of educational reform is to have students participate more actively in learning communities, including participation in formulating and evaluating questions and problems, and constructing and evaluating hypotheses, evidence, arguments, and conclusions. Abilities for participating in these activities have to be learned, and the research literature on that kind of learning is sparse. Several projects have focused on creating classroom practices of discussion and inquiry, and the investigators in those projects have discussed some aspects of the process of establishing norms and expectations by the students that support productive collaborative learning (Cobb, Wood, & Yackel, 1990; Cohen, 1986; Lampert, 1990; Slavin, 1983).

In ecological psychology, where learning involves attunement to constraints and affordances, progress in the learning of a skill can be measured by examining how the learner's performance corresponds to regularities that are important in coordinating the person's movements with relevant characteristics of the environmental system (Turvey, 1990).

Transfer. In the view of learning as coming to participate in a community of practice, transfer becomes a problematic issue. The question is whether transfer applies to new practices within the community (e.g., for school communities this might mean working new problems or accomplishing new kinds of tasks) or to practices outside the community (e.g., for school communities these might be work environments). Many of the resources and supports that occur within a community of practice do not carry over to a different community, and so the problem of transfer becomes one of marshaling the resources needed to be successful in a new environment. This requires sophisticated social and information-processing skills: the kinds of skills that businesses think they will need in the future.

In the ecological view of learning as attunement to constraints and affordances of activity, performance and learning in a new situation depend on how the learner is attuned to the constraints of activity in that situation. To analyze the problem of transfer, we need to consider (a) constraints and affordances that support activity that is learned in the learning situation, (b) constraints and affordances that support successful activity in the transfer situation, and (c) the transformations that relate the learning and transfer situations, especially which constraints and affordances remain unchanged by the transformation from the learning situation to the transfer situation. For transfer to be possible, there must be some constraints and/or affordances that are invariant under the transformations that change the learning situation into the transfer situation. For transfer to occur, the learner must become attuned to those invariants in her or his initial learning. One of the ways to be attuned is to have an abstract representation that can apply in the new situation, but this is only one possible way for attunement to occur, and it may not be the typical way for many learned activities to generalize (Greeno, Smith, & Moore, 1993).

This approach to analyzing transfer is illustrated by classic experiments concerning transfer and conceptual understanding. Scholckow and Judd (Judd, 1908) and Hendrikson and Schroeder (1941) gave boys practice in hitting a target under water. Some of the boys received an explanation of refraction of light before their target practice, others did not. The boys who received the explanation did better in transferring their skill when the depth of the water was subsequently changed. Greeno et al. (1993) interpreted the finding as resulting from an effect on the boys' attention, due to instruction about refraction, to focus on more relational features of the situation of aiming at the targets, such as apparent angular displacements of the paths of objects as they entered the water. These relational features are invariant in the transformation of changing the depth of the water, whereas other features, such as the linear displacement to use to hit the target, change.

Another example is in the results of Sayeki and colleagues' (1991) instructional experiment involving areas of parallelograms. Children were given stacks of cards that could have the shape of a rectangle or, if the cards were slid, a parallelogram. The sliding corresponded to a shear transformation that left the area constant while changing the lengths of two of the sides. The base and height of the shape, as well as the area, were invariant under the transformation. Another device given to students was a box with fixed sides that could be bent at the corners to make parallelograms with different shapes. Although the lengths of the sides were constant, the area clearly changed. Experience with these materials supported students' understanding in a way that transferred to other problems, including writing equations for areas of parallelograms, triangles, and trapezoids. Greeno et al. (1993) interpreted this finding as an example in which learning experiences can result in attunements to constraints and affordances for reasoning that remain invariant across transformations of situations.

Views of Motivation and Engagement

All of the psychological perspectives on learning school subjects assert that learning requires the active participation of students. Questions about this tend to be framed differently in the three broad perspectives, with an emphasis on *extrinsic motivation* in the behaviorist perspective, an emphasis on *intrinsic motivation* in the cognitive perspective, and an emphasis on *engaged participation* in the situative perspective.

Extrinsic Motivation: The Behaviorist/Empiricist View. In the view that learning involves forming associations, engagement is assumed to occur mainly because of extrinsic motivations—rewards, punishments, and positive or negative incentives—that affect the individual's tendency to respond in the way that is needed for learning to occur. The motivations are extrinsic in the sense that they derive from outside the individual. But their effects depend on the internal goals and needs of the individual. A reward is only effective to the degree the person receiving it wants it, and a punishment to the degree the person wants to avoid it. Engagement in activities can also be considered as a decision based on expected utilities of outcomes of the engagement, which depend on the individual's subjective probabilities and utilities regarding outcomes of alternative participation in different ways in learning activities.

Behaviorists took a primarily biological view of motivation, believing that the needs of the organism for food, water, air, sleep, and so on, and the avoidance of pain were the fundamental motives for action. They hypothesized that other motives, such as attraction to social affiliation or interesting cognitive activity, or fear of other people or situations, developed through association of these stimuli with basic biological outcomes. For example, according to the behaviorists, a subject could become conditioned to anticipate negative reinforcement on presentation of a stimulus if that stimulus was associated with painful experiences. The range of basic biological factors in motivation was debated energetically. Harlow and Zimmerman (1958) argued that infant mammals need the comfort of contact with their mothers. Berlyne (1960) argued that mammals are inherently attracted to novel situations. R. W. White (1959) argued that humans, at least, are inherently motivated to achieve mastery of tasks that present behavioral challenges. All of these arguments were supported empirically and persuaded many psychologists that extrinsic motivational factors exist that are not based on individual short-term survival.

Decision-making theory is another expression of the idea that people do what they do because of extrinsically rewarding or punishing outcomes. A decision situation is one where there are alternative actions. The decision maker is assumed to choose an action on the basis of expectations of outcomes that could follow the various alternative actions. Each possible outcome of an action is assumed to have some positive or negative *utility* for the individual, as well as a degree of expectation or *subjective probability* of occurring if that action is chosen. The *subjectively expected utility* of an action is the average of the utilities for the outcomes, weighted by their subjective probabilities. This theory assumes that people make choices that are of greatest benefit to them in the long run.

School life is filled with many different kinds of extrinsic motivations. Rewards include high grades, extra credit, gold stars, positive comments on work done, chances to perform or to do enjoyable activities, smiles, pats on the head, and other affectionate or encouraging responses from the teacher. Punishments include low grades, doing work over again, detention, letters home to parents, negative comments, being removed from the classroom or the school, frowns, and corporal punishment.

Rewards and punishments are the traditional terms used in this view of motivation. Behaviorists introduced the terms *positive* and *negative reinforcement* to emphasize their view that rewards tend to strengthen particular response tendencies and punishments to weaken particular response tendencies, or to cause negative emotional states that interfere generally with performance. When an individual is motivated to respond correctly, according to some criterion, informational feedback—also called knowledge of results—provides positive reinforcement for accurate responding and negative reinforcement for inaccurate responding, along with information to guide an adjustment in the performance for future occasions. This idea of feedback fits the connectionist view in which information fed back to the system strengthens certain connections and weakens others.

Behaviorists generally emphasized motivational issues as central to learning. In their view, learning depends on reinforcements acting to strengthen or weaken stimulus-response bonds. They argued that it was critical that the reinforcements be directly tied to particular behaviors (e.g., be close in time) in order to be most effective.

Skinner (1953) believed that negative reinforcements are often harmful to learning, because they suppress responding and can discourage people from participating lest they be punished. So he developed an approach to learning, called programmed instruction, that emphasizes positive reinforcement (Skinner, 1958). In it, students carry out tasks that increase in difficulty in very small steps, so that almost everything they do is correct. Thus, they receive almost entirely positive reinforcements during learning. The trade-off with this approach is pacing: The instruction should not move so quickly that some students make mistakes and not move so slowly that other students are bored. Computers make it possible to adjust the increments in difficulty for each individual student.

Anderson et al. (1985), though cognitive researchers, have partially incorporated Skinner's theory of programmed instruction in their intelligent tutoring systems for teaching computer programming, geometry, and algebra. Students are given tasks of slowly increasing difficulty and they are prevented from making mistakes, so that they receive mostly positive reinforcement in working with these tutoring systems.

Connectionists also treat positive and negative reinforcements as critical to learning. Learning occurs in connectionist systems based on the match between expected outcomes and actual outcomes. Some connectionist experiments employ a "teacher" to reward certain outcomes and punish others (Rumelhart et al., 1986). But in either case, learning occurs by strengthening the connections that are active when a desired outcome occurs and weakening the connections that are active when an undesired outcome occurs.

Intrinsic Motivation: The Cognitive/Rationalist View. When learning is viewed as the acquisition of knowledge and understanding of information, concepts, principles, and strategies, engagement is often considered to be a person's intrinsic interest in a domain of cognitive activity, such as music, athletics, or an academic subject. The cognitive view, with its emphasis on general concepts and methods, treats engagement in learning as an intrinsic property of the relation between individuals and the organization of information. Children are seen as naturally motivated to learn when their experience is inconsistent with their current understanding or when they experience regularities in information that are not yet represented by their schemata. This view is perhaps best exemplified in the theories of Piaget (1935,1969/1970) and Papert (1980). Unlike the behaviorist emphasis on manipulating rewards and punishments, the cognitive emphasis is on figuring out ways to foster students' natural tendencies to learn and understand.

Cognitive researchers have investigated the relations between intrinsic motivation and extrinsic motivation (Lepper & Greene, 1979). The major finding of this research has been that if people are rewarded for doing things they would choose to do for intrinsic reasons, they will no longer be willing to do them without the rewards (that is, for intrinsic reasons alone). Malone (1981) has developed a framework for intrinsic motivation in terms of three elements: challenge, fantasy, and curiosity. He attempted to characterize how to make learning environments more engaging in terms of ways to increase their challenge, fantasy, and curiosity for children. The cognitive goal is to develop learning activities that will engage students' participation in inquiry into the subject matter.

Students also differ in their participation in school learning activities based on their beliefs and understandings of themselves as knowing agents, and of what it means to know and understand. We discussed research that has characterized some of these differences in an earlier section (see p. 22).

Engaged Participation: The Situative/Pragmatist-Sociohistoric View. The view of learning as becoming more adept at participating in distributed cognitive systems focuses on engagement that maintains the person's interpersonal relations and identity in communities in which the person participates, or involves satisfying interactions with environments in which the individual has a significant personal investment. This view emphasizes how people's very identities derive from their participatory relationships in communities. According to this view, students can become engaged in learning by participating in communities where learning is valued.

An example of powerful learning of a social practice is learning one's native language in the contexts of communicating with other members of the family and community. Learning to read and write in our society is somewhat less automatic, but F. Smith (1988) argued that students will learn to read and write if they want to join the "literacy club." That is to say, if family and friends read and write, then children will want to learn to read and write. Smith noted that we all learn to speak and dress and present ourselves by our interactions with others—it is how we establish our identities. Yet our theories of school learning attempt to teach us in isolation from others by manipulating rewards and punishments, on the one hand, or by challenge and curiosity, on the other. Smith found it strange that we all believe that people learn by the company they keep, but that we have designed learning theories and environments that disregard the theory.

Lave and Wenger (1991) also treated the issue of identity as critical to their view of engagement in learning activities. An important characteristic of legitimate peripheral participation is genuine involvement in activities of the community, in which people can establish their identities in terms of functioning in the communities they join, and as they become more central to the functioning of a community, their sense of identity deriving from that community is enhanced. The motivation to learn the values and practices of the community then is tied up with establishing their identities as community members.

Educational innovations that have the goal of developing participation in social practices of inquiry and discourse can be organized to provide a community of learners to foster the engagement of students in those practices. A. L. Brown and Campione and their associates (e.g., A. L. Brown et al., 1993) organize communities of learners who collaborate on research and development of expository documents on significant academic topics, such as biology. Scardamalia and Bereiter (1991) organize communities in classes in which the members communicate concerning their discoveries and opinions about academic topics. Mathematics classrooms organized by the Algebra Project (Moses, Kamii, Swap, & Howard, 1989), Cobb et al. (1991), Lampert (1990), Schoenfeld (1987), and others are communities of practice in which students participate by thinking about mathematical topics and discussing their ideas. All these efforts emphasize creating communities where the students will develop identities as active learners with responsibility for what they learn.

Eckert (1989) focused on school culture and how different communities in American high schools (called "jocks" and "burnouts" by the students in the school Eckert studied) determine students' orientation toward school learning. The jocks adopted the school's values and hence they were engaged in ways that they recognized would result in achieving the various kinds of rewards that the school offered, such as participating in sports and performances, getting on the honor roll, and so forth. The burnouts, on the other hand, rejected the values that the school promulgated and developed a set of counterculture values and practices. Many students fell into neither of these groups, but the two communities formed an axis that was an important factor in the social organization of the school, an axis that had a major influence on students' engagement in academic learning activities, especially those involving mathematics and science education (Eckert, 1990), as well as other activities in the school.

Learning situations also present different opportunities for participation to different individuals. A teacher and other students may expect less understanding by members of a minority group or from girls than from majority students or boys, and therefore may provide fewer and less productive opportunities for them to participate in learning interactions. A provocative example was provided by McDermott (1993) in an article titled "The acquisition of a child by a learning disability," which described patterns of interaction in a classroom in which a child, the teacher, and the other children cooperated to define the child's role as one who was unlikely to understand, cooperate, or engage productively in learning activities.

Of course, effective learning involves being strongly engaged in activities that capture the learners' interests because of their intrinsic qualities as well as participation in communities. Individuals become strongly engaged in activities such as music, literature, chess, athletics, mathematics, science, computer games, and television programs, where they devote much time and energy, and their identities become invested in the growth and maintenance of abilities to participate productively in those environments. For some individuals, participation in these activities involves much group interaction; for others, it is primarily a solitary pursuit in which their social roles are defined significantly in terms of their extraordinary personal immersion in the domains of their special interests.

ISSUES OF PRACTICAL CONCEPTUALIZATION

In this section we consider three issues of educational practice: designing learning environments, formulating curricula, and constructing assessments. We consider these issues from the point of view of design experiments (A. L. Brown, 1992; Collins, 1992), which combine the goals of improving some aspect of practice and of advancing theoretical understanding of fundamental principles. The principles that are investigated are assumptions of the practice, which A. L. Brown and Campione (1994; A. L. Brown, 1994) called *first principles*. Those principles may be largely implicit in the practice, and changes in them may be required for the desired changes in practice to occur. J. S. Brown (1991) argued that investigation of such principles should be a primary objective of research and reform, in which practitioners and researchers collaborate to identify assumptions that underlie current practices as well as assumptions of practices that they would prefer, both to contribute to general understanding of how practices are organized and to identify requirements for practical change.

The principles that we consider in relation to the practical issues of this section come from the three perspectives on the nature of knowing, learning and transfer, and motivation and engagement that we developed in the foregoing section. We discuss ways in which consideration of the practical issues differs depending on the theoretical perspective that is taken, and therefore, what some of the implications of those theoretical perspectives are for these aspects of educational practice. At the same time, consideration of these practical issues sheds further light on the theoretical issues.

As an overview, we present a summary statement of the set of design principles that we then consider more specifically in the subsections that follow. We arrange these principles here by the broad perspectives on cognition and learning that put them into focus. We index these with letters associated with the perspectives: b for behaviorist, c for cognitive, and s for situative.

The Behaviorist/Empiricist View

In designing learning environments:

(b1) *Routines of activity for effective transmission of knowledge*. Learning activities can be organized to optimize acquisition of information and routine skill. In learning environments organized for these purposes, learning occurs most effectively if the teaching or learning program is well organized, with routines for classroom activity that students know and follow efficiently.

(b2) *Clear goals, feedback, and reinforcement*. For routine learning, it is advantageous to have explicit instructional goals, to present instructions that specify the procedures and information to be learned and the way that learning materials are organized, to ensure that students have learned prerequisites for each new component, to provide opportunities for students to respond correctly, to give detailed feedback to inform students which items they have learned and which they still need to work on, and to provide reinforcement for learning that satisfies students' motivations.

(b3) *Individualization with technologies*. Acquisition of basic information and routine skills can be facilitated by using technologies, including computer technology, that support individualized training and practice sequences.

In formulating curricula:

(b4) *Sequences of component-to-composite skills*. To facilitate learning of a complex but well-defined skill, the sequence of instruction should proceed from simpler components to the more complex component that they compose.

In constructing assessments:

(b5) *Assessment of knowledge components*. Tests of students' achievement in acquiring routine information and skill can be constructed by analyzing the procedures and information to be acquired and constructing items that assess students' knowledge of the components. Tests of elementary components of knowledge can be administered and scored fairly and efficiently, and can be evaluated rigorously regarding statistical properties of reliability and validity for predicting other performance that can be measured objectively.

The Cognitive/Rationalist View

In designing learning environments:

(c1) *Interactive environments for construction of understanding*. Learning environments can be organized to foster students' constructing understanding of concepts and principles through problem solving and reasoning in activities that engage students' interests and use of their initial understandings and their general reasoning and problem-solving abilities.

In formulating curricula:

(c2) *Sequences of conceptual development*. Sequences of learning activities can proceed from issues and problems that are within reach of students' initial understanding and reasoning ability to issues and problems that require greater extensions of their intuitive capabilities, accomplishing conceptual growth by refining and extending their initial understandings.

(c3) *Explicit attention to generality*. The curriculum of a subject matter domain can be organized so that students come to understand the major unifying principles of the domain. Information and problem-solving methods can be presented and discussed in ways that make their general significance and usefulness salient.

In constructing assessments:

(c4) *Assessments of extended performance*. Assessments that evaluate students' work on extended projects, or performance for which they prepare over an extended period, can provide information about significant aspects of their intellectual abilities and growth that are not available in short-answer or simple-problem tests, and can focus educational efforts on these more significant aspects of learning.

(c5) *Crediting varieties of excellence*. Assessments of understanding and reasoning need to credit varieties of excellence, which can encourage students with diverse backgrounds and abilities to contribute to the community of learners and to have their successful contributions and achievements recognized.

The Situative/Pragmatist-Sociohistoric View

In designing learning environments:

(s1) *Environments of participation in social practices of inquiry and learning*. Learning environments can be organized to foster students' learning to participate in practices of inquiry and learning and to support the development of students' personal identities as capable and confident learners and knowers. These activities include formulating and evaluating questions, problems, conjectures, arguments, explanations, and so forth, as aspects of the social practices of sense-making and learning, including abilities to use a rich variety of social and material resources for learning and to contribute to socially organized learning activities, as well as to engage in concentrated individual efforts.

(s2) *Support for development of positive epistemic identities*.

Learning environments can be organized to support the development of students' personal identities as capable and confident learners and knowers. This can include organizing learning activities in ways that complement and reinforce differences in patterns of social interaction and in expertise brought by students of differing cultural backgrounds.

In formulating curricula:

(s3) *Development of disciplinary practices of discourse and representation*. Sequences of learning activities can be organized with attention to students' progress in a variety of practices of learning, reasoning, cooperation, and communication, as well as to the subject matter contents that should be covered. Learning to participate in characteristic discourse in a domain and to use the representational systems and tools of the domain can be focused on the distinctive values and limitations of these practices, rather than on whether students correctly follow predetermined forms of discourse and representation.

(s4) *Practices of formulating and solving realistic problems*. Learning activities can focus on problematic situations that are meaningful in terms of students' experience and in which concepts and methods of subject matter disciplines are embedded. Substantial projects and long-term simulations of social activity systems can contribute to significant learning of practices of inquiry.

In constructing assessments:

(s5) *Assessing participation in inquiry and social practices of learning*. Assessments of students' abilities to participate in communities of practice require that observations of that participation should be included in the assessments of students' learning.

(s6) *Student participation in assessment*. Opportunities to participate in the formulation and conduct of assessment processes are an important aspect of fairness in assessment, and can facilitate students' development of mature judgment of and responsibility for their individual intellectual work and their contributions to the work of groups in which they participate.

(s7) *Design of assessment systems*. Assessments can be designed as systems that take into account the effects of assessment on the learning environments and teaching interactions of school activity, and that support the demanding requirements of human evaluation that are required for meaningful assessment of students' progress in learning.

Designing Learning Environments

Many design experiments in education are focused on learning environments that are organized by a set of assumptions about the nature of knowing and learning and that provide information for evaluating the validity of those assumptions.

Information Transmission and Training Environments: The Behaviorist/Empiricist View. Traditional classroom learning environments are designed on the principles of the behaviorist view of knowing and learning. They are organized with the goal of students acquiring a maximum accumulation of organized information and procedural knowledge. They are designed to support interactions in which information can be efficiently transmitted to students by teachers, textbooks, and other information sources. Reading, attending to a teacher's presentations, listening to radio broadcasts, and watching television, film, or videotape, are all forms of learning activity in environments that are organized to transmit information efficiently.

Traditional classrooms are also designed to support acquisition of routine skills. Correct procedures are displayed and opportunities are provided for rehearsal and practice, including practice that is done as homework, which may be checked and recorded during class sessions. The assumption that learning is the acquisition of associations supports arranging interactions in which components of information or procedures are presented systematically, taking into account what the students already know, and monitoring closely whether students have acquired the intended components before going ahead. Programmed instruction and computer-based drill-and-practice programs are designed to provide well-organized information and procedural training that is sensitive to individual students' progress through a prescribed course of study.

(b1) *Routines of activity for effective transmission of knowledge*. Across seven decades of theory and practical curriculum development, behaviorists have stressed the centrality of controlled practice on the elements of knowledge in the content domains. Research that has studied teaching and learning in didactic environments has confirmed the assumptions of behaviorist theory regarding conditions that favor learning of components of information and routine skills (see Brophy & Good, 1986, for a review). For behaviorists, it is the job of the curriculum and the teacher to organize the students' practice: to choose the materials students will use, schedule practice, and make sure appropriate rewards for practicing and learning are available. Students learn by carrying out the practice activities embodied in instructional materials and organized by teachers. Questioning by students or student efforts to organize learning activities for themselves play little role—except insofar as they motivate themselves and organize their time to practice in the ways laid out by teachers and materials.

(b2) *Clear goals, feedback, and reinforcement*. Behaviorist accounts stress the importance of rewarding correct responses to the practice items, although there have been rather heated debates about what constitutes reward. For example, feedback that informs students that a response was correct can function as a reward if the students are already motivated to learn that response, but not if they are indifferent to performing correctly. In general, effective use of reinforcement requires understanding of students' motivations and choosing reinforcers that are relevant to those motivations.

There have been differences of opinion over whether punishment of any kind is needed or appropriate. Skinner's behaviorism distinguished between punishment (a specific negative consequence) and extinction (no environmental reaction to an incorrect response), and psychologists working in the behaviorist tradition worked hard to arrange sequences of practice that would produce *errorless learning* (Terrace, 1966). The notion was that any practice of a wrong association would tend to strengthen it, even if there was some negative consequence. In addition, it was believed that punishment would produce negative reactions to, and thus avoidance of, the learning situation as a whole. The effort to avoid having students make errors was what gave programmed instruction its repetitive character.

Anderson et al. (1985; also see M. W. Lewis & Anderson, 1985), after testing the possibility of allowing students to explore incorrect sequences in solving a problem, found that their intelligent tutoring systems were more effective if students were required to follow one of the paths that the computer expert system could recognize—in effect, requiring practice of correct associations only. Anderson's tutors present students with graded sequences of whole proofs to build or equations to solve. They prevent student errors through the capacity of the intelligent computer program to detect errors "on-line," as the student works through the multiple steps of the problem.

Performance of correct responses is more likely if the situation does not include irrelevant stimuli that could distract the students. Behaviorist curricula, therefore, have presented the elements to be practiced in simple contexts, which do not have many of the features of everyday situations in which the responses could occur usefully. For example, the Thorndike (1917–1924) arithmetic textbooks, and the subsequent generations of texts and workbooks influenced by his theories, provide pages of drill on addition or multiplication without any problem or use contexts. The expectation in behaviorist curricula is that, once learned to a high standard of reliability, elements of knowledge can be called on in many different contexts. More complex contexts of practice make it harder to control the practice, and especially to avoid errors.

Research on information processing has provided additional results about learning environments that can support students' learning correctly. When the learning task is to assimilate information provided in texts, students are able to acquire that information better when they are given clear indications of the way the information is organized and are helped to learn how to use the organization of text information in their studying (Chambliss & Calfee, 1996). When the task is to learn how to solve routine problems, students are better able to learn problem-solving methods when strategic aspects of the method are presented explicitly in interactive computer environments (Anderson et al., 1985).

(b3) *Individualization with technologies*. If basic information and skills have functions in meaningful activities, we can expect many students to value opportunities to strengthen their abilities to perform them. Teachers can provide materials for transmitting and training basic information and skills with traditional work sheets and homework assignments. Alternative methods have become available, however. For symbolic skills such as arithmetic operations, manipulation of formulas, word problems, and proof exercises, computer-based systems for drill and practice (e.g., Suppes & Morningstar, 1972) can provide training in which exercises are chosen to be appropriate for individual students' level of skill and knowledge. Intelligent tutoring systems can diagnose and remedy specific kinds of errors and provide information that helps students understand the solutions of problems (Wenger, 1987).

A significant possibility exists for using computer systems in the way that practice rooms and training facilities are used in many learning environments. Computer systems for transmission and training can be valuable as resources to provide much of the routine training that currently occupies much of the time and effort of teachers.

Problem-Solving and Exploratory Environments for Conceptual Understanding and Reasoning: The Cognitive/Rationalist View. The views of knowing and learning as conceptual understanding and general thinking abilities suggest that didactic learning environments can have unintended negative learning outcomes, even when they succeed in their functions of transmitting information and training procedural knowledge efficiently. Although basic information and skills are valuable and sometimes necessary for achieving expert levels of performance in significant activities of reasoning and problem solving, they are often taught as ends in themselves, rather than as resources for more meaningful activities. Wiggins (1989) likened this common practice to requiring prospective soccer players to practice dribbling, passing, and shooting without ever providing opportunities to play a game of soccer. Schoenfeld (1985) found that students develop distorted beliefs about the nature of mathematics, for example, that mathematical problems are typically solved within one or two minutes.

In the constructivist view, which emphasizes general conceptual understanding and thinking abilities, the reasons for disillusionment with didactic learning environments are mainly empirical. Considerable effort in didactic teaching is aimed at students' understanding of general concepts. The difficulty is that didactic teaching of concepts does not result, for most students, in general understanding. Most students who learn to recite definitions and formulas that express the meanings of concepts in general terms, or to carry out procedures with numbers or formulas, show limited proficiency in solving problems and understanding other situations in which those concepts or procedures could be used.

(c1) *Interactive environments for construction of understanding*. Behaviorist psychology recognizes the need for learners to be *active*—that is, to actively practice the bonds and associations laid out by experts. This is a very different meaning of active learner than we see in constructivist psychological theories. Constructivist learning environments are designed to provide students with opportunities to construct conceptual understandings and abilities in activities of problem solving and reasoning.

The activities of constructing understanding have two main aspects: interactions with material systems and concepts in the domain that understanding is about, such as interacting with concrete manipulative materials that exemplify mathematical concepts such as place value or fractional parts, and social interactions in which learners discuss their understanding of those systems and concepts. To be successful, a learning environment must be productive in both of these aspects. Most of the design experiments that have been done, however, have placed their primary emphasis on either the material aspect or the social aspect.

Several studies have focused on providing students with material systems, including physical materials and computational technologies. The designers of these systems have generally thought of them in terms of the constructivist idea of developing conceptual structures. On the other hand, they can also be considered from the point of view of ecological psychology in the situative perspective. In a situative view, understanding a concept is considered as being attuned to constraints of activity that a community treats as constituents of that concept (Greeno, 1995). The material and computational systems that we discuss here are designed with conceptual constraints built into the systems, so that by learning to interact successfully with the systems, students can become attuned to those constraints and thereby gain implicit understanding of the concepts.

Brownell's (e.g., 1935) studies of meaningful learning emphasized use of concrete materials to exemplify mathematical ideas, an approach that has been used extensively in elementary school mathematics teaching. Rods of lengths corresponding to numbers have been used to teach concepts of addition and subtraction (Gattegno, 1963). Sets of blocks or beads have been used to teach addition and subtraction of multidigit numbers (Dienes, 1966; Montessori, 1917/1964). Multiplication and division are explained using rectangles, and fractions are explained using regions, partitioned into equal subregions, with some number of the subregions distinctively colored. Many research studies have examined ways in which use of concrete, manipulative materials can enhance students' understanding and learning of correct procedures. The results of one study, by L. B. Resnick and Omanson (1987), suggested that an important role may be played by discussion of the meanings of manipulations of the concrete materials, rather than simply showing how the procedures work with the concrete materials and numerical symbols.

Materials such as place-value blocks and fraction circles are considered concrete because they have properties that correspond to mathematical ideas more directly than numerical symbols do. On the other hand, such materials are also abstract, in that they represent idealized objects that are designed to display mathematical properties much more directly than they appear in most situations. Nesher (1989) distinguished between *exemplifications* and *applications*, that is, between materials designed to display mathematical properties directly and situations in which mathematical principles and operations can be used to make inferences about realistic systems. Nesher argued for teaching concepts initially with exemplifications, in order for students to grasp the concepts clearly, and for teaching students to solve applications problems later.

A classic example of the use of concrete materials to learn a mathematics concept was given by Wertheimer (1945/1959). The example involved the concept of the area of a parallelogram. Wertheimer observed a class in which the teacher presented the formula for the area of a parallelogram, area = base × height, with directions for applying the formula to calculate the area of drawn parallelograms. Wertheimer discerned that this instruction may not have resulted in a kind of conceptual understanding that students might achieve; and he described, as an alternative, interactions he had with elementary students that began with a concept of area they already had, the number of square tiles that cover a rectangular shape. Wertheimer asked about the area of a parallelogram, and some students perceived the way in which a parallelogram can be transformed to a rectangle, providing understanding of the relation among the base, height, and area of a rectangle.

A different instructional activity for this concept was devised by Sayeki et al. (1991), who gave students stacks of paper that formed rectangular surfaces at the end of the stacks. The students experienced changes in the shapes of those end surfaces by sliding the papers to make different angles between the base and sides. This transformation does not change the area of the parallelogram at the end surface—it is composed of the same set of edges, just arranged differently—and it does not change the height, but it changes the lengths of the sides of the parallelogram. Sayeki and colleagues' instruction can provide understanding by helping students become attuned to a constraint—the relation of height, base, and area of a parallelogram—that is invariant when a shear transformation is applied. They provided evidence of this understanding by asking students to construct formulas for the area of a parallelogram and other polygons, and many students succeeded in these tasks.

Interactive computer programs can support activities in which students construct understanding of concepts by manipulating and observing simulations. A learning environment for high school geometry is the Geometric Supposer (Schwartz, Yarushalmy, & Wilson, 1993), which has a computer interface that enables students to construct diagrams of geometric figures such as triangles or parallelograms. Numerical values of some of the quantitative properties of these figures are specified, and the program provides the numerical values of other properties. Students can change the values of some properties and observe whether other properties, or relations between properties, change or remain constant. Activities that use the interface are arranged to invite students to form conjectures about conditions in which some properties are invariant and to try to construct proofs that support those conjectures.

Simulations have been designed that allow students to control objects in a simulated Newtonian world without friction, and with gravity absent or in a controllable and inspectable form (diSessa, 1982; Roschelle, 1992; B. Y. White, 1983, 1993). Software used for investigating concepts in thermodynamics (Linn, 1992) uses a thermometer attached to a computer and graphs temperature as a function of time. The thermometer can be placed in a liquid that is being heated or cooled. and students can observe the graph of heating or cooling that occurs in different conditions. For example, two containers of liquid with different volumes can be heated to the same temperature, and the slower rate of cooling in the larger volume of liquid can be observed graphically, encouraging the understanding of cooling as a phenomenon of loss of heat, distinct from loss of temperature (Linn, Songer, Lewis, & Stern, 1993; see also chapter 15, this volume).

A simulation of heat exchange developed by Wiser and Kipman (1988) represents substances as collections of small particles that move more or less rapidly, depending on the temperature. Larger volumes of a substance have more particles, and therefore have greater amounts of motion at the same temperature than smaller volumes. The software simulates heat exchange by showing how a heat source changes the motion of particles near the source and the changes in the motion diffuse through the substance, taking longer if there is more of the substance to change.

Another example, developed by Pea and Goldman and their associates (Goldman, in press; Pea, Sipusic, & Allen, in press), emphasizes use of a standard scientific representational system in the domain of geometric optics. A graphical interface was developed that supports construction of ray diagrams, with light sources and objects that absorb, refract, or reflect light. Students use the interface to construct diagrams of situations in which they explore properties of light, such as shadows and the convergence of rays to form coherent images. Unlike standard instruction, in which construction of diagrams is a task that students need to learn to perform, this system presents diagrams as a resource for understanding phenomena and concepts in the domain. This provides opportunities for students to practice using the representations for inquiry.

In more complex settings, computer displays have been designed to provide visual support for the acquisition of mental models—that is, cognitive representations that support reasoning and understanding by simulating the behavior of systems in the world (e.g., Johnson-Laird, 1983). These simulations allow students to learn important knowledge and skills in contexts that they could never participate in naturally, to see features that are invisible in real environments (e.g., the center of mass, the inside of pipes), to control variables that are not possible to control in life, and to see these in action, unlike static text figures.

B. White and Frederiksen (1990) developed software that represents relations of electrical voltage, resistance, and current in a series of increasingly sophisticated mental models. In a training system for engineers who are learning to operate the power plant of a large ship, various components of the system, such as boilers, valves, pipes, and engines, are shown, with visual properties that represent relevant properties such as pressures and temperatures (Stevens & Roberts, 1983). The display simulates results of operating on the system in various ways, such as turning on a boiler. By interacting with the computational system, a learner can develop abilities to simulate the effects of operations in a model of the power plant.

Sherlock (A. Lesgold, Lajoie, Bunzo, & Eggan, 1988) is another system designed for learning mental models in training electronic maintenance technicians. Sherlock presents simulations of a complex electronic diagnostic system behaving with various malfunctions that learners have to diagnose. The learners apply tests and obtain information about readings that would be obtained. Learners' interactions with Sherlock are designed to facilitate their developing mental models of tests, including their functions in providing information relevant to the problem-solver's search in a large space of possible malfunctions and their symptoms (see chapter 24).

Environments for Learning to Participate in Social Practices of Inquiry and Sense-Making: The Situative/Pragmatist-Sociohistoric View. We need to understand school learning environments in two ways: their effects on the subject matter knowledge and ability that students acquire, and their effects on the kinds of learners that students become. Students adapt to the practices of school learning positively or negatively. Those students who become engaged participants learn to participate in the activities that constitute their school's practices of learning.

Students acquire practices of learning by participating in classroom and homework activities, but the practices they acquire may not be those that are intended or valued by the teacher, the school, or the society. Practices are learned as individuals participate in activities of communities. They are not uniform—different members of communities act in different ways, and any individual acts differently in different circumstances. But significant aspects of activity that are recognized and valued in a community are learned by individuals as they interact with others, learning to coordinate what they do with others.

(s1) *Environments of participation in social practices of inquiry and learning.* Many educators and researchers are making efforts to develop and understand learning environments in which students' participation results in their learning to be more active in social processes of constructing understanding. The activities that students can learn to participate in include formulating and evaluating questions, problems, hypotheses, conjectures, and explanations, and proposing and evaluating evidence, examples, and arguments.

In this section we discuss studies that have focused mainly on aspects of learning environments involving social interaction, particularly discourse practices. In the situative view, an important part of learning the concepts of a domain is learning to participate in the discourse of a community in which those concepts are used. For example, an important part of understanding the mathematical concept of fraction is knowing how to talk about properties and relations of fractional quantities and how to use mathematical representations of fractions to communicate and reason. By participating in discourse in a domain, students should also become attuned to forms of explanation and argumentation that are standards of practice in the domain.

As we mentioned previously, both the social and the material aspects of learning environments are crucial for their support of conceptual growth. In the learning environments that we discuss now, material systems, including concrete exemplifications of mathematical concept, demonstrations of physical phenomena, and diagrams and other symbolic representations, play a critical role.

Learning environments for strengthening students' general skills in thinking, such as Philosophy for Children (Lipman, 1985, 1991) are organized as communication environments in which students learn practices of formulating questions and alternative positions on traditional philosophical issues, such as meaning, truth, aesthetics, reality and imagination, and ethics, that arise in the context of stories.

Students' classroom experiences differ in different subject-matter classes. For example, learning activities in many mathematics and science classes are more didactic and hierarchically authoritarian than are social studies classes or literature classes that the same students attend (e.g., Stodolsky, 1988). Schoenfeld (1988) identified beliefs that students derive from their experience in working on mathematics problems: for example, if the answer is not an integer, it is probably wrong; all the problems at the end of a chapter use the methods introduced in the chapter; if you cannot solve the problem in a couple of minutes, you probably do not know how to solve it; and so forth. Schoenfeld argued that most of these beliefs are counterproductive for learning to think mathematically as well as for problem solving in life, in addition to reflecting a grotesquely mistaken view of problem solving of the kinds that mathematicians engage in.

There have been several very successful examples of how effective group discussions can be as learning environments in classrooms. Classroom discourse can be organized so that students learn to explain their ideas and solutions to problems, rather than focusing entirely on whether answers are correct. In projects involving mathematics education, Cobb and his associates (e.g., Cobb et al., 1991) have worked with teachers in designing and working out classroom activities in first- and second-grade arithmetic. Much of the students' activity involves working in pairs, with the expectation that they will discuss how to solve problems and understand each others' ideas. Attention is given to norms of discourse, particularly involving respectful attention to others' opinions and efforts to reach mutual understanding. Results support the expectation that the quality of the students' explanations becomes more sophisticated and substantive as they engage in the practice.

In Lampert's (e.g., 1990) fifth-grade classroom, students offer proposed answers to questions that Lampert presents. Many of the questions are designed to elicit multiple answers and therefore to provide occasions for resolving different opinions. Lampert frequently asks the class to discuss one of the students' thinking about a problem, focusing on assumptions that may have led to a conclusion that other students did not reach. It is quite common, at the end of a discussion, for one or more of the students to say that they have "revised their thinking." Lampert works to establish that offering an opinion is helpful to the class discussion, whether or not it turns out to be correct, and that changing one's mind should be considered valuable, but that there should be mathematical reasons for changing one's mind, rather than just agreeing with someone else's view.

L. B. Resnick, Bill, Lesgold, and Leer (1991) developed an approach to teaching problem solving in arithmetic to "at-risk" elementary schoolchildren. The approach relies on encouraging children to use their own invented procedures, to bring problems from outside of school that they discuss in class, and to introduce formal notation and key mathematical structures as early as possible. Classroom activities have the form of discussions of problem situations, such as different ways to divide some cupcakes among the members of the class. As in the mathematics instruction that is standard in Japanese schools (Fernandez, Yoshida, & Stigler, 1992; Stigler & Perry, 1988), a considerable amount of time is spent developing understanding of one or a few problems, rather than focusing on skill in computational procedures. Although it might be thought that this shift would result in decreased learning of the standard computational material of the mathematics curriculum, the method led to dramatic increases (from the 30th to the 70th percentile) on California achievement tests, compared to students who were taught earlier by the same teacher using a more traditional approach.

A notable implementation of a discussion method in science education is the Itakura method (Hatano & Inagaki, 1991), in which students are asked to make different predictions about what will happen in an experiment. They then discuss and defend among themselves why they think their predictions are correct. After any revisions in their predictions, the experiment is performed and discussion ensues as to why the result came out the way it did.

The Jigsaw technique developed by Aronson (1978) provides a method of organizing school learning to facilitate communication activities among students. In it students break into groups, each of which learns about a different topic. Then the students regroup, so that there is one expert on each topic in each group, and the students then teach each other about all the topics. A. L. Brown and Campione and their associates (Brown et al., 1993) have developed a variant on the Jigsaw technique they call JIGSAW2. Groups of students research topics such as pollution or endangered species in order to prepare a booklet on each topic. Then, when they have written up their findings, they regroup to work with other students who are reading the booklets produced. The reading groups are run using the reciprocal teaching method (Palincsar & Brown, 1984), where the student who worked on each booklet acts as a teacher, getting other students to generate questions, summaries, clarifications, and predictions about the text.

The CSILE environment developed by Scardamalia and Bereiter (1991; Scardamalia, Bereiter, & Lamon, 1994) is a discussion environment where students communicate in writing over a computer network. They first formulate questions they want to investigate (e.g., "Why can humans speak when apes cannot?") and then each student in the group makes a conjecture about what he or she believes. Then they all start investigating the question, finding whatever relevant information they can from source materials and typing that into the system for others in the group to read. They also can receive commentaries written by an expert in the problem domain who monitors the notes that the students have written. Through written discussions they refine their theories for publication in the system to all the students in the class. Students frequently refer to their explanations with the phrase "my theory," and present arguments and questions for their own and other students' positions.

An environment that is organized to facilitate learning cognitive skills is the Fifth Dimension, developed by Cole and his colleagues (Laboratory of Comparative Human Cognition, 1982). Middle school students participate in an after-school club in an environment that has a rich variety of cognitively challenging activities, most of which are in gamelike formats. The students work with young adults—university students who do this as project work in a communications class—who provide general guidance and encouragement. They also communicate using electronic mail with a "wizard," who provides written advice and commentary. The progress that students make is recorded in terms of levels of skill they have achieved in the various activities they work on, and as they advance in skill, they hold tickets that permit them to engage in more advanced versions of the activities. The Fifth Dimension recruited students who were unsuccessful in standard school instruction, and many of them made remarkable progress in their cognitive capabilities through their participation.

Environments for remote discussion are becoming available in the form of electronic networks. During the past several generations, many friends and members of families have constructed learning environments by exchanging correspondence and conversing by telephone. Recently, remote conversational learning has expanded significantly for some people through electronic mail and fax machines. Several experiments now underway are exploring the potential for students in different locations to learn through exchanges of electronic messages (e.g., Reil & Levin, 1990).

(s2) *Support for development of positive epistemic identities.* Students in a classroom, like participants in any community, learn practices of participating in the activities of communities in the school setting. Some students learn to participate in ways that are recognized and valued by the teacher and the school. Some students learn to participate in ways that involve minimal engagement in activities that are officially recognized, but may have considerable value in the communities of their peers. These differences relate to ways in which individuals define their roles in the institution of learning, partly on the basis of the relations between those institutions and the communities in which they participate. These communities may be integrated well with the goals and practices of the institution or they may be antagonistic toward the institution, and this can create major differences in the ways that the various learners participate in the institutional learning activities.

An example was provided by Eckert (1989) in her ethnographic study of the social organization of a high school in which she identified well-defined groups that called themselves "jocks" and "burnouts." Differences between the groups included ways in which knowledge and information were understood and used. The jocks treated information as a commodity; to them, knowing something was a sign of success. Burnouts shared information, and contributing information to others was valued social participation. This difference in the social role of information was a significant factor, for example, in the courses that burnouts chose: Practically none of them elected courses in mathematics or science, where intellectual work is typically highly authoritarian, individualistic, and competitive (Eckert, 1990).

Families and communities in different cultural groups interact in different ways, and children from different cultural groups bring different resources of knowledge and custom to the situation of schooling. Learning activities in schools can be organized so that diverse styles and expertise are resources for enriching the learning experiences of all of the students. For example, Tharp (1989) discussed instructional methods adapted to children's different cultural styles, such as the use of a spoken story format with Hawaiian children and an emphasis on cooperative activity with Navaho children. Moll and his associates (Moll, Tapia, & Whitmore, 1993; Moll & Whitmore, 1993) studied a whole language bilingual classroom in which students and the teacher collaboratively chose themes for extensive study and in which students who differed in their familiarity with historical events contributed productively in discussions to their groups' understanding.

The Algebra Project (Moses et al., 1989) is an educational reform in mathematics organized around the central idea that all students should develop strong capabilities and strong identities as knowers of mathematics. Moses is particularly concerned about mathematics, which functions as a strong selection factor in U.S. society. The Algebra Project is organized to provide middle school students with opportunities to be prepared and confident in their abilities to take high school algebra. In its initial version, in Cambridge, Massachusetts, the Algebra Project emphasized community organization, an effort to establish a consensus including the school and the parents of students that all students should and could become able mathematics learners for whom high school algebra would be appropriate. The curriculum of the Algebra Project is focused on providing experiences that students share and that can be used as material for developing mathematical concepts and notations, as we discussed earlier.

Programs designed to assist selected groups of students can be informed by understanding of their different social practices of learning. An example involving university students was provided by Triesman (1990), in the Professional Development Program to assist African-American students at the University of California at Berkeley, particularly in their mathematics course work. Such programs often provide remedial instruction, assuming that minority students have not received adequate high school instruction in the subject matter. Such programs rarely do more than enable students to pass courses minimally, and Triesman had higher aspirations. He conducted a study in which he observed the learning activities of several African-American students, which he compared with the learning activities of several Asian-American students. He discovered that the African-American students almost always studied individually, while the Asian-American students spent much of their study time working in groups, where they shared understandings of course requirements and strategies of learning and taking tests, as well as understandings of course material. The Professional Development Program now encourages and facilitates African-American students in organizing groups of students who work together in their learning activities, as well as conducting sessions in which students work on problems that are among the hardest that will be included in course materials, rather than limiting their material to problems needed to succeed minimally.

Formulating Curricula

A curriculum asserts a set of educational goals and a sequence of learning activities that are intended to promote development toward those goals.

Curricula for Accumulating and Tuning Connections: The Behaviorist/Empiricist View. The leading theorists of empiricism throughout the 20th century have themselves applied their theories of knowledge and learning to the problem of the school curriculum. As a result of this direct engagement by leading research scientists, including Thorndike (1922), Skinner (1958), Gagné (1965), and Anderson (Anderson, Boyle, Corbett, & M. W. Lewis, 1990), empiricist theories have had a substantial and continuing influence on curriculum practice. Empiricist-inspired curricula span teaching technologies from the drill-and-practice workbook to the intelligent, computer-based tutor. In all of these examples, we can find similar types of activities, based on similar views of the relations between teacher, student, and instructional materials, and similar conceptions of how learning activities should be sequenced and participation controlled.

Empiricist theories of knowledge and learning assume that the task of the learner is to acquire the body of connections that an expert analysis of the subject matter reveals. Associationist and behaviorist psychologists have not, by and large, considered their science as capable of shedding light on the basic questions of what is worth knowing. Rather, they have accepted the school subjects as more or less established and have sought to show how they could be most efficiently acquired by students.

(b4) *Sequences of component-to-composite skills.* A major contribution of behavioral task analysis has been to support a successful technology of instructional design in which procedural and factual knowledge is divided into components that are arranged in a learnable sequence. Typical sequences of instruction begin with training in a procedure, facts, or vocabulary in a simplified context, followed by presentations of the material in somewhat more complicated settings. Standard mathematics textbooks are examples, in that procedures for calculating are presented and practiced, followed by word problems. Under the assumptions of this sequential learning scheme, it is important that students have mastered the simpler components to be ready to learn the more complex behaviors.

Empiricist-inspired curricula organize most practice as rehearsal of individual elements of knowledge or skill. In Anderson and colleagues' (1985) tutors, where rather complex sequences of proof or algebraic manipulations are being taught, evaluation of student responses proceeds on a step-by-step basis. After simpler components of vocabulary, facts, or procedures have been mastered, more complex units are presented. The mastery approach is a central feature of Gagné's (1968) and other learning hierarchy approaches to curriculum.

This method is widely used in the design of technical training and in corporations (see, e.g., Reigeluth, 1983) and its ideas are informally used in the design of some school curricula, especially in mathematics. A theoretical analysis by VanLehn (1990) used arithmetic subtraction as an example and developed a computational model of learning in which he showed that conditions such as adding only one subprocedure per lesson and showing the learner all relevant intermediate results are important enabling conditions to support learning of correct procedures.

Curricula for Conceptual Understanding and General Abilities: The Cognitive/Rationalist View

(c2) *Sequences of conceptual development.* The theme of meaningful learning, where "meaningful" has tended to imply a focus on organizing concepts of a field of knowledge, has been a dominant counterweight to empiricist theories throughout the history of educational psychology. Although behaviorists have had significant influence on mainstream curriculum practice, including the organization of textbooks and testing, a stream of research in the 20th century has focused on identifying organizing themes and concepts and studying how students can best come to understand them. Gestalt psychologists (e.g., Katona, 1940) searched for organizing structures in human perception and thinking. Much of their work was focused on perceptual structures, often taken to be biologically determined ways in which individuals were attuned to the physical environment. A few Gestalt psychologists, most notably Max Wertheimer (1945/1959), proposed that there also exist organizing *conceptual* structures, and that these, rather than collections of specific associations, should become central in the school curriculum.

Research on conceptually meaningful learning has been most influential when psychologists have allied with subject matter specialists and have become deeply engaged in efforts to define curriculum in a particular subject, rather than concentrating on more generic theories of learning or instruction. Examples include the work of Brownell (e.g., 1935), who in the 1930s studied processes of meaningful learning in mathematics, stressing the role of understanding of concepts in promoting more stable computational performance, and Schwab's (1978) discussions of the structures of subject matter domains.

In the 1960s psychologists such as Bruner (1960) joined forces with a broad community of scientists and mathematicians in efforts to develop curricula grounded in the fundamental concepts of those disciplines. Central in Bruner's thinking was the question of how the complex concepts of scientific and mathematical disciplines could be made accessible to children at different stages of cognitive development. Bruner's optimism about the possibilities—he argued that any concept could be taught in some intellectually honest form to children at any age—brought him into some theoretical conflict with Piaget, whose extensive body of work on children's cognitive development was, in the 1960s, just coming to the attention of American psychologists and educators (as discussed earlier in the second section, p. 18).

Piaget himself never wrote about curriculum as such. Indeed, his constructivist theory of knowledge—the theory that individuals do not absorb or copy ideas from the external world, but rather must construct their concepts through active observation and experimentation—led him to argue against direct teaching of disciplinary concepts (Piaget, 1935,1965/1970). What he was arguing against was direct teaching of the behaviorist bits-and-pieces variety, rather than the kinds of meaningful learning that psychologists such as Brownell and Bruner advocated. But Piaget's advocacy against direct teaching led many developmental psychologists to argue for a curriculum based almost entirely on children's construction of knowledge by direct interaction with elements of the physical environment (e.g., Ginsburg & Opper, 1969).

One educational result of Piaget's influence was that, for a considerable period of time, psychologists collaborated with science educators on an approach to curriculum that deliberately separated processes from content. Although Piagetians did not believe that specific science concepts could be directly taught, many, especially in America, believed that the processes of scientific reasoning could be. Curricula—such as *Science: A Process Approach*—were developed to teach children specific skills for observation, experimentation, data analysis, and the like, and avoided commitment to any specific knowledge.

Subject matter domains also contain general methods of reasoning and problem solving, which can be taught in ways that emphasize their general usefulness. An approach to general methods of reasoning and problem solving was encouraged by work in information processing, especially the characterization of general methods in programs such as the General Problem Solver (Ernst & Newell, 1969; Newell & Simon, 1972). In the spirit of the General Problem Solver and its claim that a limited set of strategies and heuristics could be applied successfully in all or most domains of knowledge, most programs for teaching problem-solving skills were initially "add-ons" to the standard subject matter curriculum. In educational terms, they belonged to the "study skills" strand of curriculum, embodied in special courses, often optional and often designed for students who were not performing at optimum levels, or for individuals interested in raising their own levels of performance (e.g., Hayes, 1981; M. Levine, 1988).

In the spirit of study skills courses, most thinking skills programs went beyond the cognitive strategies revealed by information-processing research to include a variety of self-management skills, including procedures for managing one's own time and motivation for study. These *metacognitive* abilities soon became an object of educational research and experimentation as well, especially in the field of reading comprehension. Two streams of curriculum thinking based on metacognition emerged. One was quite similar to the information-processing strategy programs. Children were taught about strategies for comprehending texts and the strategies themselves were the focus of practice, classroom conversation, and, quite often, tests. Most efforts to directly teach metacognitive skills and other deliberate learning strategies have been disappointing. The taught skills often are not retained, are not applied independently by students, or take a brittle form that does not seem to enhance other learning, even when the new strategies themselves are performed to specification. A repeated finding is that general strategies directly taught to students tend not to be spontaneously used under conditions different from those in which they were initially practiced (e.g., A. L. Brown & Campione, 1977).

On the other hand, there have been several demonstrations of successful instruction in strategic aspects of learning and problem solving when these were connected with the kinds of contents and activities that are contained in subject matter domains. An example was provided by Schoenfeld (1985), who developed an instructional approach designed to integrate the learning of general mathematical principles and their application to particular problems. His goal was to teach students general problem-solving heuristics, patterned after ideas of Polya (1945), such as constructing a simpler version of the problem and using analogies. He also taught metacognitive control strategies, such as considering alternative courses of action and monitoring to see whether you are making progress toward a solution. Finally, he emphasized teaching productive beliefs about problem solving. His teaching methods involved students solving many different kinds of problems, first as a whole class with him acting as facilitator, then in groups of three or four where he acted as a monitor, and finally alone as homework. Similar approaches to learning much earlier mathematics through problem solving, invention, and discussion are also being developed (e.g., Carpenter, Fennema, Peterson, Chiang, & Loef, 1989). (See p. 31).

An example of this approach in reading is reciprocal teaching (Palincsar & Brown, 1984). Reciprocal teaching maintains focus on the content of the texts but organizes special procedures to help children learn to monitor their comprehension by summarizing, asking questions, or predicting what might come next in the story.

Learning activities focused on strategic know-how also have been designed in writing and arithmetic. In learning to write, students often focus on the contents of their compositions, neglecting rhetorical factors that are crucial for their writing successfully. Bereiter and Scardamalia (1987) created an environment in which students commented on their own texts, choosing from a set of cards with statements such as "I need another example here," or "Even I seem to be confused about this," or "This is very clear." Computational environments for learning strategies were designed by J. S. Brown and Burton, including strategic aspects of playing a game to gain proficiency in arithmetic (Burton & Brown, 1982), and strategies of troubleshooting involved in choosing tests in electronic maintenance (J. S. Brown, Burton, & deKleer, 1982). These systems, like Bereiter and Scardamalia's cue cards, involve intervention in a student's work with strategic hints or requirements that they give strategic reasons for their actions.

These subject matter–based problem-solving programs represent an effort to resolve in curriculum terms the fundamental tension between what Newell (1980) called *weak* methods—i.e., general skills—and *strong* methods—i.e., domain-specific procedures, as we discussed in a previous section. Many studies have shown that students' abilities to understand and learn new material depend strongly on what they already know (Glaser, 1984). Nevertheless, it appears that educators cannot build expertise by having their students memorize experts' knowledge. That kind of learning appears to produce "inert" knowledge (Whitehead, 1916), unlikely to be usable in complex performances. Instead, expert knowledge must be constructed through activity and experience. Knowledge construction, however, is time-consuming. The social and personal mental elaboration necessary for successful learning takes time—much more time than is typically allowed for the study of any topic in the school curriculum. This means that efforts to cover an extensive body of knowledge are bound to fail to produce significant learning. In response to this understanding, several leading thinkers have promoted a philosophy of "less is more" (e.g., Sizer, 1992; Whitehead, 1916)—that is, learning a few important ideas and concepts well is educationally more powerful than is a curriculum of extensive but superficial exposure. This has begun to engender a research agenda concerned with identifying powerful, generative concepts—the ones to include in the "less" curriculum—and with figuring out how to teach them so that they are, in fact, generative. This research on the generative curriculum is being pursued subject matter by subject matter, most often in collaborative teams that include cognitive researchers and subject matter experts.

The cognitive perspective brings psychologists into much more active contact with subject matter or disciplinary experts than has been the case for those working in the behaviorist perspective. Investigators using the cognitive approach did not initially raise questions about the content of the curriculum but gradually—partly through their own interest in the structure of information, and partly through the attraction of information-processing concepts and methods to some researchers in science and mathematics education—cognitive psychologists began to ally with subject matter specialists and with other branches of psychology that had long treated the structure of knowledge itself, and the ways in which people come to appreciate and use different knowledge structures as the central questions of the discipline.

Findings of research in which students are asked to explain phenomena that are theoretically problematic and in which their explanations have been interpreted as misconceptions (e.g., McCloskey, 1983) can be interpreted as raising problems for the constructive/rationalist assumption. Students may not have reached a sufficient operational stage to reason effectively, or their intuitions may be discrepant from expert understanding. On the other hand, our earlier discussion of research on children's conceptual growth (see p. 18) showed significant abilities to reason intuitively in conceptual domains, which suggests that classroom activities should build on the initial understandings of children. This can be achieved if the phenomena that we want students to understand can be presented in a way that affords students' understanding them in ways that can be extended toward expert understanding. To accomplish this, we need to find ways to activate versions of understanding that can serve as bases of the target understandings.

One example is a kind of lesson that Minstrell (1989) and A. L. Brown and Campione (1994) call a *benchmark lesson*.

Benchmark lessons are used to introduce conceptual problems that are known to present difficulties for students, and to elicit the students' understandings of situations in which the scientific concepts apply. Those phenomena then are used as foci of discussion for which alternative interpretations are developed, as extensions and transformations of the students' initial understandings. In another example, Roth (1986) reorganized the presentation of material in middle school biology texts to address students' initial understanding of plant nutrition as a process of ingestion, and related the idea of photosynthesis to the intuitive understanding that students have about manufacturing.

Students' initial understandings can also be brought to bear by using analogies in which the constraints of the system being studied are salient, as in D. E. Brown and Clement's (1989) use of a spring analogy to help students understand about normal forces. While it is counterintuitive for many students to think of a surface such as a table as exerting a force on a resting object, it is intuitive to think of a spring as exerting such a force. Then the system of a surface supporting an object can be thought of by analogy with the spring, by recognizing that there is a small compression of any surface when an object is resting on it. D. E. Brown and Clement hypothesized that in learning through analogies, students are able to develop mental models of systems that are attuned to the important causal constraints of the systems they are studying.

The principle of connecting instruction with students' understanding is also reflected in the activities involved in the learning environments that we discussed earlier (see pp. 29–33). When physical materials and computational environments are designed to represent conceptual structures, the representations are chosen to enable students' intuitive understandings to serve as a basis for developing their understanding of subject matter concepts. When classroom activities are organized to promote students' active construction of understanding through participation in discourse, problems and examples are used that evoke students' intuitive understandings, which are then appropriated for productive discussion and analysis in the class.

Curricula for Learning Participation in Social Practices: The Situative/Sociohistoric View. According to the situative view, the curriculum should reflect a set of commitments about kinds of activities that students should learn to participate in, as well as the subject matter contents that they should learn about.

(s3) *Development of disciplinary practices of discourse and representation.* Subject matter disciplines have characteristic forms and styles of discourse, including ways in which questions, hypotheses, and conjectures are formulated and related to accepted knowledge and ways in which evidence, examples, and arguments are related to conclusions. They also have characteristic forms of representation that are used productively among practitioners. The curriculum of a subject matter domain can be organized to include students' coming to appreciate and learning to participate in these forms and styles of discourse and representation.

Formal arguments involving explicit definitions and postulates are concentrated in the high school geometry course. In typical instruction, students study proofs of theorems and learn to construct proofs in exercise problems. This gives them little or no experience in formulating the definitions and choosing postulates that the proofs depend on.

In a classic design experiment, Fawcett (1938) organized a high school geometry class around practices of deductive reasoning. The class engaged in discussion of alternative ways of defining terms and the necessity of stating assumptions explicitly for an argument to be formally valid. An important aspect of reasoning practices in mathematics is the attention given to explicit definitions and statements of assumptions. Fawcett led his class in discussions of alternative definitions, emphasizing relations between definitions of concepts and the uses of those concepts in constructing proofs. They also emphasized premises and conclusions of arguments, considering whether stated premises were sufficient to support claims as deductive consequences or whether additional assumptions were needed for some claims. Discussions included topics of geometry, where each student constructed a system of defined concepts and postulates that he or she used to prove a set of theorems. Discussions also included topics from everyday activity, which involved practices of examining definitions of concepts and validity of arguments from the point of view of mathematical rigor. For example, at the beginning of the term Fawcett noted that the school had decided to give an award to a "good citizen" at the end of the year, and his class discussed the problem of defining the concept of a "good citizen" sufficiently to support a decision of which student should be the winner.

The general point of Fawcett's example is that students learned practices of formulating mathematical definitions and arguments, learned how to judge the validity of mathematical claims, and learned to take responsibility for making and questioning mathematical assertions. For most students, learning these aspects of practice in a discipline requires a setting in which they can participate in the kinds of activities in which the discipline engages. Unless teachers organize the activities of learning to include participation in inquiry and discourse about concepts, claims, and arguments, with students having responsibility for their claims and questions, we cannot expect more than a few students to acquire these aspects of practice in subject matter disciplines.

Similarly, in Schoenfeld's (1987) course in problem solving, a major goal is for the students to develop standards of adequate argumentation. When they do so, they do not depend on the instructor to tell them whether a solution is correct or whether an argument they have developed is a valid proof.

In most instruction in behaviorist or cognitive approaches, technical representations are presented to students as systems they need to learn, and they need to learn to use those representations correctly. An alternative is to organize activities in which students will construct representational systems, thereby participating in discussions in which the meanings and functions of symbols are the results of their inquiry rather than simply a task for them to learn. In one example, diSessa, Hammer, and Sherin (1991) observed a teacher and a class develop several graphical representations that revealed students' intuitions about speeds of motion as a vehicle goes up a hill, stops, and rolls back down. A rich variety of graphical representations was developed in which students could learn to appreciate features such as continuity that characterize the standard system of graphing. In the Algebra Project (Moses et al., 1989), one of the ways that students have agency in their learning of mathematics is in developing their own symbols for mathematical relations such as the direction of a displacement in space, related to the sign of an integer.

The principle of introducing discourse practices of a discipline to students through their participation is reflected in all of the learning environments where students provide explanations of their opinions and arguments to support their conclusions.

(s4) *Practices of formulating and solving realistic problems.* In several design experiments, psychologists and educators are working to develop curriculum materials and activities in which students' learning experiences are focused on meaningful settings of activity in which the contents of subject matter disciplines are embedded. These activity structures engage students' interests and understandings, and support learning that extends their ability to reason with subject-matter concepts.

In one example, the Jasper project at Vanderbilt (Cognition and Technology Group at Vanderbilt, 1990, 1994; see also chapter 25) creates engaging videotape presentations of problem situations. One concerns someone finding an injured eagle in a location that can be reached only by helicopter, creating a problem that includes minimizing the time it will take to reach the site and transport the eagle to a place where it can receive care. The problems reflect the complex problem solving and planning that occurs in real life and provide opportunities for using mathematical methods to reason about significant aspects of a problem situation, rather than merely exercising mathematical procedures mechanically. Another example is the Middle-School Mathematics Through Applications Project at the Institute for Research on Learning in Palo Alto (Moschkovich, 1994), which creates computer-based learning environments in which students work on design problems, such as designing living and working space for a research team in Antarctica.

Projects are an attempt to bring research, design, and troubleshooting tasks from work environments into the school. For example, Dewey (Cuban, 1984) had students in his laboratory school build a clubhouse for the school, where they learned planning, mathematical, and construction skills. In Boston, Harel (1991) had fourth graders each develop a computer program to teach third graders about fractions. In Rochester, New York, eighth-grade students carried out research projects on the city of Rochester and on the life and times of George Eastman (Carver, 1990; Collins, Hawkins, & Carver, 1991) by interviewing adults and finding source materials. Their findings were produced as HyperCard stacks, which were displayed at the Rochester Museum and Science Center.

Project environments challenge the scope-and-sequence notion of curriculum because students typically need a wide variety of skills to carry out any project. These skills can be taught either before or during the project, and resources should be provided for students to learn how to do the things that are needed to proceed through their project work.

These projects are raising the fundamental issue of contents and cognitive processes in a strong form. Their activity settings are engaging and meaningful, and students participate actively in complex cognitive processes of problem formulation, understanding, and reasoning. These processes depend on principles of the subject matter disciplines, and students succeed and grow in their abilities. The subject matter concepts and principles, however, tend to be embedded in the contexts of their activity settings. It is a particular challenge to provide for students' learning of systematic knowledge in subject matter domains when the curriculum is organized by realistic and extended projects.

A crucial topic for research, then, is to improve our understanding of relations between subject matter concepts and reasoning that relies on those concepts. An issue for curriculum analysis and formulation will be to develop learning agendas that give appropriate emphasis to both explicit and implicit understandings of subject matter concepts and principles that students can gain.

Constructing Authentic Assessments

Assessment is integral to education in that it serves to guide the teaching and learning process and reports to parents and the public. The problems of assessment and testing have been central ones for educational psychology throughout its history. The development of theories and techniques for reliable and efficient testing is one of educational psychology's most important practical achievements. However, these theories and techniques have been developed almost entirely within only one of the three views of knowing and learning that we have discussed in this chapter, the behaviorist/empiricist view. This has led in recent years to calls for developing new approaches to assessment that are in better accord with the epistemological assumptions of the cognitive and situative views.

Whether an assessment of knowing and learning in a domain is authentic depends on whether it does what it claims to do—that is, to inform us about knowing and learning in that domain. Therefore, any evaluation of authenticity depends on the view of knowing and learning that the evaluation presupposes. The three views of knowing and learning that have organized our discussion support quite different views of assessment. The traditional behaviorist perspective supports a quantitative view of knowing and learning, in which assessment involves independent samples of knowledge or skill to estimate how much of the domain a student has acquired. The cognitive view of assessment emphasizes questions about whether students understand general principles in a domain and whether they use methods and strategies that are useful in solving problems in the domain. The situative view of assessment emphasizes questions about the quality of students' participation in activities of inquiry and sense-making, and considers assessment practices as integral components of the general systems of activity in which they occur.

Measuring Elements of Acquired Information and Skill: The Behaviorist/Empiricist View

(b5) *Assessment of knowledge components.* In the behaviorist view, knowing in a domain is a collection of information and skills that a person has acquired. A mature technology supports the construction of achievement tests, which are used in assessments in many schools, states, nations, and international studies. The development of these tests relies on participation by knowledgeable experts in the subject matter disciplines of the test who provide authoritative judgments that the items in the test accurately represent knowledge in the discipline. A combination of expert judgment and empirical results is used to characterize the difficulty of items. The development of tests also is supported by the technology of analyzing tasks in the domain in terms of component procedures and prerequisites.

Technologies of psychological measurement arose from Binet's work in the early 20th century (1909). When Binet was asked to identify students who needed special help in school, he constructed a broad sample of items intended to measure ability. The tests that he developed, and that have been developed in the tradition of psychological measurement, consist of large sets of items, most of which can be answered quickly. This allows a broad sampling of intellectual activities of different kinds to be included in the test, but with little or no opportunity for sustained work on any complex problem or understanding any complex idea. Because intelligence has been viewed as an attribute of individual capability, primarily involving manipulation of symbols, tests do not include observation of an individual's interactions with other people or with complex mechanical or other environmental systems. Binet's test was designed for individual, clinical administration. Subsequently, considerable effort was devoted to creation of pencil-and-paper intelligence tests, made up of multiple short items, that could be administered to groups and scored mechanically.

Tests of multiple intellectual competencies (e.g., Guilford, 1967; Thurstone, 1938) have involved identifying factors of ability, such as spatial, verbal, or numerical ability. Such a test consists of a collection of items that relate to the ability that it is purported to measure, with the same properties of brevity and unambiguous scorability as characterize items on tests of general intelligence.

The techniques originally developed for intelligence tests were also applied to tests of knowledge and achievement in school subjects. *Standardized* achievement tests are typically based on large samples of small items that represent a broad range of content, but with tasks that do not include sustained work on complex problems, communication or collaboration with other people, or complex interactions with complex mechanical or other environmental technologies. The achievement tests in widest use in U.S. schools also use item selection techniques that are designed to compare students with each other in a process of *norm referencing*, rather than with an explicit standard of what students are expected to learn. A newer technology of *criterion referencing* (Glaser, 1994) has attempted to match test items to explicit learning expectations, but by and large it has maintained the atomistic nature of the individual test items.

Tests of ability or knowledge composed of atomistic items make sense if we assume that the question we need to answer is some version of "How much?"—that is, how much general intelligence does a student have? or how much ability of a more specific kind, such as spatial or verbal ability, does a student have? or how much does a student know in some domain such as mathematics, history, or biology? This method of measuring school achievement makes sense in the behaviorist perspective, which assumes that acquired knowledge consists of an accumulation of components of information and skill, and the question "How much has a student learned in this subject matter?" is answered meaningfully by scores on tests that sample the elements of that domain.

Measures of students' general intellectual abilities and background knowledge provide information that is used to predict their prospects for successful learning in traditional school and school-like settings. Entrants into the U.S. military, for example, take a test that measures several aspects of intellectual ability, and the results are used to assign inductees to training programs of various kinds. Most standardized achievement tests are constructed in the multiple-choice format, which supports both objectivity and efficiency in scoring. By the use of multiple-choice items and machine scoring, scores can be compared across the world, and tests can be judged against standards of statistical reliability and validity in predicting students' future performance in schools.

Evaluating Growth in Reasoning and Understanding: The Cognitive/Rationalist View

(c4) *Assessments of extended performance.* When knowing is viewed as the ability to employ general reasoning schemata and strategies and understanding of general principles in domains, assessment emphasizes students' knowing and reasoning in accomplishing larger tasks. Short-answer tests can assess whether students can answer questions about general principles, but many people argue that to assess whether students can reason with and communicate about general principles, it is necessary to observe them in appropriate activities of reasoning and communication. Alternative assessments that are being developed include on-demand examination questions that take an hour or more of class time, projects that take several days or weeks, and portfolios of work that is accomplished throughout a term or year of study.

Psychologists working in the Piagetian tradition and educators studying learning in subject matter domains have developed assessments to evaluate children's levels of logicodeductive functioning and conceptual development, which have been used mainly in their research studies. These assessments typically use interview techniques and experimental methods that uncover children's conceptions and misconceptions in science and mathematics. (For example, see chapters in Carey & Gelman, 1991, or in M. Gardner, Greeno, Reif, Schoenfeld, diSessa, & Stage, 1990.) These approaches have not seen widespread use in school assessment, in large part because they are time-costly, relying on clinical interviewing or special experimental arrangements and individualized interpretation.

The argument for assessments based on more complex performances is essentially the same as that for assessing writing based on performance of students in writing tasks. Some years ago the English-language teaching community rebelled against short-answer items as a way to measure writing ability, based on the argument that it is impossible to assess writing ability without having students write. They developed several systematic scoring methods, in particular, holistic scoring, analytic scoring, and primary-trait scoring (Huot, 1990). Referees are systematically trained to make reliable judgments on a 4- to 6-point scale. It is possible to obtain very high interrater reliability in scoring (around 90%) with practice (Huot, 1990; Mullis, 1980). Similar techniques are used for Advanced Placement examinations and to assess portfolios for advanced placement in the arts.

These developments, having solved some of the problems of objectivity in scoring assessments based on extended performances, have begun to be used as the basis for developing new technologies of *performance assessment* in education (Mislevy, 1993; L. B. Resnick, 1994). Performance assessment provides a bridge between the cognitive and the situative perspectives on knowing and learning, because the extended performances needed to assess conceptual understanding and reasoning often also involve engagement with other people and with tools and artifacts that create natural, or "authentic," situations of activity.

An important example of this use of technology is the manner in which the introduction of video and computers into schools made it possible to consider assessing abilities that are not well captured in written performances (Collins, Hawkins, & Frederiksen, 1993). For example, videotape can record students' oral presentations, their work with other students, and their execution of hands-on activities. Computers can record information about students' problem solving in real-world contexts (e.g., playing the role of a bank teller), their responsiveness to hints and feedback, and their long-term learning in different task contexts. These two media make it possible to assess aspects of student performance that paper and pencil inherently cannot record.

(c5) *Crediting varieties of excellence*. An important contribution of psychologists working in the rationalist tradition has been a reformulation of the theory of multiple intellectual competencies with a focus on understanding and meaning (H. Gardner, 1983). An implication of this perspective is the importance of recognizing multiple approaches that students may use to solve problems and preferences that students may have for particular contents and styles of mental work. Understanding and reasoning occur in the contexts of activities that shape them and give them significance, and if they are addressed to a significant issue, there will always be multiple ways for an intellectual contribution to be productive.

The need to recognize multiple kinds of contributions means that evaluations of student work need to be made by individuals and groups of judges who are sensitive to the varieties of excellence that can occur. As psychologists and educators develop systems of evaluation and assessment, we can contribute to the valuing of diversity in the styles and methods of understanding and reasoning that develop within our society.

Assessing Participation in Practices: The Situative/Pragmatist-Sociohistoric View

(s5) *Assessing participation in inquiry and social practices of learning*. When knowing in a domain is considered as ability to participate in the socially organized distributed practices of thinking and inquiry in the domain, assessment needs to be focused on evaluation of those abilities. Many of the proposals for alternative assessments, such as evaluation of projects and portfolios (e.g., Resnick & Resnick, 1991) are relevant to the assessment of participation in inquiry practices, because those materials are relatively direct products of inquiry. It is also valuable to base assessments on observation of work by individuals and groups in significant inquiry activities. These assessments can involve evaluations of the quality of activity of groups of students and their individual members in the course of their work on projects. It can also involve observation of students' work on problems that are presented for the purposes of assessment, sometimes called "on-demand" assessment.

(s6) *Student participation in assessment*. An important aspect of participation in a community involves being included in the community's processes of evaluation of its accomplishments and progress. The situative view of knowing and learning, therefore, supports the notion that students should participate meaningfully in the processes of assessment, not merely as people whose work is assessed, but also as contributors to the formulation of standards and judgments of quality of work. Participation in processes of assessing their own and other students' work can provide opportunities for them to develop their own standards, their abilities for intellectual judgment, and their sense of personal responsibility for their individual work and their contributions to the community's progress.

(s7) *Design of assessment systems*. The central issues around educational assessment concern its role in the overall system of schooling (Frederiksen & Collins, 1989). Many feel that it is the most powerful lever reformers have on the system and that if we can construct an assessment system that encourages thinking, then schools will change teaching practices (Resnick & Resnick, 1991). A contrasting view is that the educational system has evolved with assessment as one component, and that if assessment practices are changed independently of other components (curriculum, pedagogy, textbooks, etc.), then the system will force new assessment practices back toward current practice to fit with the other components (Cuban, 1984).

Human judgments of intellectual work play a crucial role in the kinds of evaluation of students' learning that are most significant. To accomplish the reforms that are needed in assessment of school learning, we need to develop systems of assessment practice in which the judgments that are produced can be interpreted and trusted. We believe that this requires development and support of communities of practice in assessment that will develop standards of evaluation as well as standards of quality in the work of students that they evaluate. This will be an important aspect of the professional work of teaching, and, like other aspects of teaching that are implied by the reforms of education, will have to be supported as an integral part of teachers' activity. As a part of this effort, research can be addressed to understanding the complex ways in which teachers and students generate and use information about the achievements and progress of students as inherent aspects of their everyday activities of classroom work (Hall, Knudsen, & Greeno, in press).

CONCLUSIONS

We have presented our understanding of the current state of knowledge in educational psychology regarding the central issues of cognition and learning. We hope that we have conveyed both a sense of continuity in the development of research on these topics over the course of the 20th century and a sense of the transitional state that we believe the field is in at this time. We also hope that we have conveyed our belief that concepts developed in this research have both progressively enriched and deepened the scientific understanding of fundamental processes and significantly supported the understanding and improvement of educational practice. In this concluding section, we consider prospects for the continued development of the theoretical perspectives and research involving design experiments.

Theoretical Issues

We have portrayed the theoretical state regarding cognition and learning as being organized by three general perspectives, all with long traditions, whose current versions we have called behaviorist, cognitive, and situative. These perspectives are not equally developed, of course. The behaviorist perspective was the main line of development in the psychology of learning for several decades. Development of the cognitive perspective became the major focus of psychological research on learning and thinking in the 1970s. And the situative perspective is still in an early stage of development as an organizing principle and set of work practices for psychological research.

We expect that in the next several years, one of the salient theoretical questions for this field will be the continuing clarification of relations among these three perspectives. In broad terms, there are at least two ways that this may develop.

One possibility is that the behaviorist, cognitive, and situative views analyze processes of cognition and learning at different levels of aggregation. A behaviorist analysis studies activities of individuals. A cognitive analysis is more detailed, studying individual activity at a level of its internal structures of information, including symbolic representations and processes that transform symbolic expressions. A situative analysis is more aggregated than a behaviorist analysis. A situative analysis studies activity systems in which individual agents participate as members of social groups and as components of larger systems in which they interact with material resources. Viewing the relation among these perspectives as focusing on different levels, we would expect theoretical developments that show how principles of activity at the level of groups and human resource systems can be understood as compositions of principles of individual behavior, along with principles of group and human resource interaction, and how principles of individual behavior are compositions of principles of information processing, along with other principles such as motivation and emotion.

Another possibility, involving a somewhat more competitive relation among the perspectives, is that the situative perspective can provide a kind of synthesis of the behaviorist and cognitive perspectives. According to this possibility, behaviorist analyses study processes of activity, neglecting their contents, while cognitive analyses study contents of activity, including processes that transform those contents, but neglect processes that must be included if activity is to be understood as being affected by and affecting systems other than individual agents. According to this view, the three perspectives may constitute a kind of Hegelian cycle of thesis–antithesis–synthesis (Greeno & Moore, 1993), in which behaviorism provides a thesis that focuses on external aspects of activity, the cognitive view provides an antithesis that focuses on internal informational aspects, and the situative view may develop as a synthesis that unifies the strengths of the two earlier approaches. This view supports an expectation of theoretical developments that will show how principles of individual behavior and of information processing can be understood as special cases of more general principles of interactive functioning.

Issues of Understanding and Facilitating Practice

In our discussions of issues of educational practice, we have tried to show how the theoretical perspectives that we considered can be used to understand principles that are inherent, as assumptions, in current practices or in practices that people want to have. In our view, the role of theory in practice is not to prescribe a set of practices that should be followed, but rather to assist in clarifying alternative practices, including understanding of ways that aspects of practice relate to alternative functions and purposes of activity. We believe that the educational principles that are expressed in alternative theoretical perspectives can all be valid as bases of practice. Alternative principles can be complementary, but they can also be in conflict. The challenges of practice involve finding patterns of activity that advance multiple values when they are compatible and balance values when they are inconsistent.

The principles articulated in this chapter are first approximations, and further critical discussion may lead to clearer and more coherent expressions of practical assumptions. We also recognize that the issues that we have discussed—learning environments, curriculum, and assessment—are a small subset of the issues that are critical in educational practice. We believe that other issues also can be informed by the kind of discussion we have begun to develop in this chapter, perhaps organized by the same theoretical perspectives that we have used.

As one example of such a prospect, consider issues of teaching practice. The behaviorist perspective suggests a focus on efficiency of conveying information and training skill, and emphasizes teaching practices that involve well-organized routines of classroom activity, with clear plans and goals. The cognitive perspective suggests focusing on teaching as a kind of coaching, emphasizing teachers' understanding of and attention to students' thinking in order to identify potential improvement that they can guide and encourage. The situative perspective suggests a focus on teachers as mentors who represent communities of practice in the society. As such, they engage in the professional activities of creating and using disciplinary knowledge, exemplify valued practices of these communities, and guide students as they become increasingly competent practitioners.

As another example, consider issues of valuing diversity among students. The behaviorist perspective suggests a focus on equity of access and opportunity to acquire valued knowledge and supports development of practices that ensure that all students can achieve a satisfactory level of basic knowledge. The cognitive perspective suggests a focus on differences among students in their interests and engagement in the concepts and methods of subject matter domains, in the understandings that they bring to school activities, and in their learning strategies and epistemological beliefs, and supports development of practices in which these multiple interests, understandings, and approaches are resources that enrich the educational experiences of all students. The situative perspective suggests a focus on school learning as the activities of communities of practice whose members—the teachers and students—are participants in many communities outside of school, and whose main function is to help prepare students for satisfying and effective participation in multiple communities of the society in their later lives. This perspective encourages the development of social arrangements in school that can reinforce and complement students' family and other nonschool social communities and the development of students' and teachers' identities through meaningful participation in social and professional communities that create and use subject matter knowledge.

Needless to say, discussions of these and other crucial educational issues require much careful thought and attention to the diversity of practical and theoretical work that has been and is being carried out regarding them. Our hope and belief is that discussions along these lines may contribute to that work.

Advancing Practical Theory

We are convinced that there is a significant shift occurring in the relation between theoretical and practical work and progress in educational psychology. We have focused much of our attention in this chapter on a kind of research that includes developmental work in designing learning environments, formulating curricula, and assessing achievements of cognition and learning and, simultaneously, on efforts to contribute to fundamental scientific understanding. In research and development of this kind, questions about a theory are not limited to whether it is coherent and yields accurate predictions; we also ask, as a central question, whether it works—that is, do the concepts and principles of the theory inform practice in productive ways. It becomes a task of research to develop and analyze new possibilities for practice, not just to provide inspiring examples, but also to provide analytical concepts and principles that support understanding of the examples and guidance for people who wish to use the examples as models in transforming their own practices.

This trend is not a simple combination of traditional basic and applied research. It involves a different conceptualization of what research and practical reform are. We believe that, as A. L. Brown and Campione (1994; A. L. Brown, 1994) and J. S. Brown (1991) have argued, reforming practices requires transformations of people's understanding of principles that are assumed—perhaps implicitly—in the practices, and that theoretically oriented research can assist in identifying those principles and suggest ways of accomplishing the transformations. At the same time, we believe that by embedding research in the activities of practical reform, the theoretical principles that are developed will have greater scientific validity than those that have been developed primarily in laboratory work and in disinterested observations of practice, because they will have to address deeper questions of how practices function and develop.

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