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CHAPTER 2

Foundations and Opportunities for an Interdisciplinary Science of Learning

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In this chapter, we argue that the learning sciences are poised for a "decade of synergy." We focus on several key traditions of theory and research with the potential for mutually influencing one another in ways that can transform how we think about the science of learning, as well as how future educators and scientists are trained.

The three major strands of research that we focus on are: (1) *implicit learning and the brain*, (2) *informal learning*, and (3) *designs for formal learning and beyond*. As Figure 2.1A illustrates, these three areas have mainly operated independently, with researchers attempting to apply their thinking and findings directly to education, and with the links between theory and well-grounded implications for practice often proving tenuous at best.

The goal of integrating insights from these strands in order to create a transformative theory of learning is illustrated in Figure 2.1B. Successful efforts to understand and advance human learning require a simultaneous emphasis on informal and formal learning environments, and on the implicit ways in which people learn in whatever situations they find themselves.

We explore examples of research from each of these three strands. We then suggest ways that the learning sciences might draw on these traditions for creating a more robust understanding of learning, which can inform the design of learning environments that allow all students to succeed in the fast changing world of the twenty-first century (e.g., Darling-Hammond & Bransford, 2005; Vaill, 1996).

Implicit Learning and the Brain

Implicit learning refers to situations in which complex information is acquired effortlessly (without a conscious effort), and the resulting knowledge is difficult to express verbally (e.g., Berry, 1997; Cleeremans, Destrebecqz, & Boyer, 1998; Reber, 1967). Although many types of implicit learning exist, a common process underlies most of them – the rapid, effortless, and untutored detection of patterns of covariation among events (Reber, 1993).

Implicit learning is pervasive across many domains, including influences on social attitudes and stereotypes regarding gender and race (Greenwald, Banaji, Rudman, Farnham et al., 2002), visual pattern learning (Musen & Triesman, 1990), motor response time tasks (Nissen & Bullemer, 1987), syntactic language learning (Reber, 1976), phonetic language learning (Goodsitt, Morgan, & Kuhl, 1993; Kuhl, 2004; Saffran, Aslin, & Newport, 1996), and young children's imitative learning of the tools, artifacts, behaviors, customs, and rituals of their culture (Meltzoff, 1988a; 2005; Rogoff et al., 2003; Tomasello, 1999). Implicit learning has educational and even evolutionary value inasmuch as it enables organisms to adapt to new environments by listening, observing, and interacting with the objects and people encountered there, even in the absence of formal pedagogy or a conscious effort to learn.

What Can Neuroscience Add to the Study of Learning?

Research correlating brain and behavior has a long history, but the 1990s were designated "The Decade of the Brain," and advances took place in neuroscience at an especially rapid pace. Three dominant methods for measuring brain activities are (1) *ERPs* – event-related potentials – which track changes in the electrically evoked potentials measured on the surface of the scalp; (2) *fMRI* – which tracks changes in blood flow in the brain; and (3) *MEG* – which tracks magnetic field changes in the brain over time.

Educators and policy makers rapidly recognized the prospects for education of new neural measures of mental activity. In July 1996, the Education Commission of the States and the Dana Foundation held a conference entitled "*Bridging the gap between neuroscience and education*," convening leaders from the two fields. Many argued that the gap between the neuron and the classroom was substantial, perhaps a "bridge too far" (Bruer, 1997). Research since that time has begun to close this gap.

There are three reasons to include cognitive neuroscience in the learning sciences. First, a mature science of learning will involve understanding not only *that* learning occurs but also understanding *how* and *why* it occurs. Neuroscience measures reveal the internal mechanisms and biological substrates of learning, and this enriches our understanding of how learning occurs. Second, the combination of fMRI, ERPs, and MEG provide useful information about the temporal unfolding and spatial location of the brain mechanisms involved in learning and memory. Third, because of their sensitivity, neuroscience measures may be helpful in understanding individual differences in learning. Cognitive neuroscientists can peek below the behavioral output to the generators of that behavior; brain and behavioral data taken together will enrich our understanding of learning (Gopnik, Meltzoff, & Kuhl, 1999).

Some Fundamental Brain Findings and Their Implications

It is a common misconception that each individual's brain is entirely formed at birth and that "the brain basis" of behavior reveals fixed aspects of human cognition. Instead, experiences during development have powerful effects on the physical development of the brain itself. A pioneering study of the effects of the environment on brain development was conducted by William Greenough and his colleagues (Greenough, Black, & Wallace, 1987). They studied rats placed in various environments and the effects on synapse formation in the rats' brains. They compared the brains of rats raised in "complex environments," containing toys and obstacles and other rats, with those housed individually or in small cages without toys. They found that rats raised in complex environments performed better on learning tasks, and had 20–25 percent more synapses per neuron in the visual cortex. Brain development is thus "experience-expectant" – evolution has created a neural system that "expects" information from the environment at a particular time, allowing

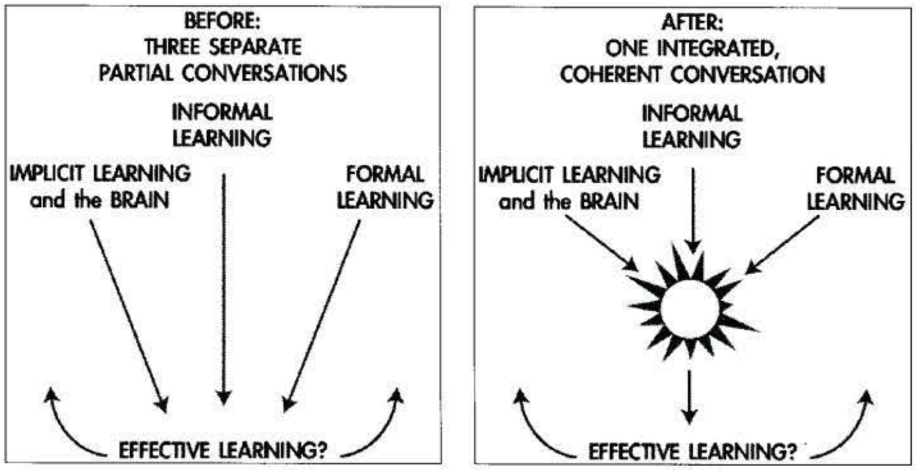

Figure 2.1 A and B. Toward an integrated, coherent conversation.

animals to acquire knowledge that is specific to their own environments when exposed to that information. These experiments suggest that "rich environments" include those that provide numerous opportunities for social interaction, direct physical contact with the environment, and a changing set of objects for play and exploration.

ASSUMPTIONS ABOUT CRITICAL PERIODS FOR LEARNING

Several brain researchers have hypothesized that humans' brains are preprogrammed to learn certain kinds of knowledge during a limited window of time known as a *critical period*. But the latest brain science is beginning to question this simplistic developmental notion. For example, new brain research shows that the timing of critical periods differs significantly in the visual, auditory, and language systems. Even within different systems, there is emerging evidence that the brain is much more plastic than heretofore assumed, and that the idea of rigid "critical periods" does not hold.

New studies by Kuhl and colleagues explored potential mechanisms underlying critical periods in early language development (e.g., Kuhl, Conboy, Padden, Nelson, et al., 2005; Rivera-Gaxiola et al., 2005). The idea behind the studies relies on the concept of *neural commitment* to language patterns. Kuhl's recent neuropsychological and brain imaging work suggests that language acquisition involves the development of neural networks that focus on and code specific properties of the speech signals heard in early infancy, resulting in neural tissue that is dedicated to the analysis of these learned patterns. Kuhl claims that early neural commitment to learned patterns can also constrain future learning; neural networks dedicated to native-language patterns do not detect non-native patterns, and may actually interfere with their analysis (Iverson, Kuhl, Akahane-Yamda, Diesch, et al., 2003; Kuhl, 2004; Zhang, Kuhl, Imada, Kotani, et al., 2005). If the initial coding of native-language patterns interferes with the learning of non-native patterns, because they do not conform to the established "mental filter," then early learning of one's primary language may limit second language learning. By this argument, the "critical period" depends on *experience* as much as time, and is a *process* rather than a strictly timed window of opportunity that is opened and closed by maturation.

The general point is that learning produces neural commitment to the properties of the stimuli we see and hear. Exposure to a specific data set alters the brain by establishing neural connections that commit the brain to processing information in an ideal way for that particular input (e.g., one's first language). Neural commitment functions as a filter that affects future processing (Cheour et al., 1998; Kuhl, 1991; Kuhl, Williams, Lacerda, Stevens, et al., 1992; Näätänen, Lehtokoski, Lennes, Cheour, et al., 1997), and results in highly efficient processing of learned material (Zhang et al., 2005). The most studied example is *language*, where neural filters affect processing at all levels, making native-language processing highly efficient and foreign-language processing difficult for adults (Strange, 1995). In adulthood, second language learners have to overcome committed brains to develop new networks.

LEARNING IN INFANCY BEFORE NEURAL COMMITMENT: NEUROPLASTICITY

In a recent illustration of how the brains of infants remain open to developing neural commitments to more than one "mental filter" for language experiences, Kuhl and colleagues tested whether American nine-month-old infants who had never before heard Mandarin Chinese could learn the phonemes of Mandarin by listening to Chinese graduate students play and read to them in Mandarin Chinese (Kuhl, Tsao & Liu., 2003). Nine-month-old American infants listened to four native speakers of Mandarin during twelve sessions in which they read books and played with toys. Then infants were tested with a Mandarin phonetic contrast that does not occur in English to see whether exposure to the foreign language would reverse the usual decline in infants' foreign-language speech perception. Infants learned during these live sessions, compared with a control group that heard only English, and American infants performed at a level statistically equivalent to infants tested in Taiwan who had been listening to Mandarin for eleven months. The study shows how readily young infants learn from natural language exposure at this age.

Children's Implicit Learning from other People: Imitative Learning

Children learn a great deal outside of formal learning settings simply from watching and imitating other people. This is important for the transmission of culture from parents to children and for peer-group learning. The laboratory study of imitative learning has undergone a recent revolution, revealing that we are the most imitative creatures on the planet, imitating from birth (Meltzoff & Moore, 1977) and learning from imitation beyond other primates such as monkeys and chimpanzees (Povinelli, Reaux, Theall & Giambrone., 2000; Tomasello & Call, 1997; Whiten, 2002).

Recently, the importance of imitative learning has been underscored by the discovery of "mirror neurons" that are activated whether a subject performs an action or sees that action performed by another (e.g., Rizzolatti, Gadiga, Fogassi & Gallese, 2002; Meltzoff & Decety, 2003). Clearly, imitative learning involves more than the presence of mirror neurons, and neuroscientists are trying to determine the special abilities – perhaps uniquely human abilities such as perspective taking and identification with others – that support our proclivity for learning by observing others.

Ample research shows that young children learn a great deal about people and cultural artifacts through imitation, and children are influenced not only by their parents, but also by their peers and what they see on television. For example, one study showed that fourteen-month-old infants learn from and imitate their peers in daycare centers (Hanna & Meltzoff, 1993). Another showed that two-year-olds learn novel actions from watching TV (Meltzoff, 1988b). This is an important finding because young children in Western culture watch a good deal of TV: a Kaiser Foundation report (Rideout, Vanderwater, & Wartella, 2003) indicates that almost 70 percent of children 0–3 years old watch television on a typical day and 58 percent do so *every* day.

The next decade of research in neuroscience will focus on the relationship between behavioral development and brain development. One thing has been established without a doubt – learning experiences help sculpt an individual's brain. Brain development is not a product of biology or culture exclusively, but, more accurately, a complex interaction of both.

Informal Learning

Here we outline the second strand of research, the processes and outcomes of informal learning. *Informal learning* usually takes place outside of school. The important distinction here is not the physical location where learning occurs but, rather, the contrast between informal learning and the explicitly didactic instructional practices that have emerged in Western schooling, which we refer to as formal learning. Informal learning can be pervasive in peer-to-peer interactions within school, and formal learning may take place in noninstitutional settings such as community centers, or during an "instructional moment" when a parent mimics didactic instruction.

Informal learning has been studied in work settings, museums, zoos, aquariums, community centers, sports teams, Girl Scout troops, and among communities without formal schooling (Bransford et al., in press; Hull & Shultz, 2001; Schauble, Leinhardt, & Martin, 1998). We begin with a brief summary of insights from a broad range of researchers who investigate learning out of school and then move to a discussion of why the study of informal learning is a crucial area for the learning sciences.

Cognitive Consequences of Schooling and Contrasts in Learning Settings

In a widely cited *Science* paper, Scribner and Cole (1973) reviewed many comparative cultural studies using cognitive and developmental methodologies to examine thinking and reasoning processes. The distinctions they inferred from the empirical literature between the forms of thinking, acting, and learning in formal education and informal practical life are echoed in later influential writings by Lave (1988), Resnick (1987), and others, right up to today's contemporary research at and across the boundaries of informal and formal learning. Their thesis is that "school represents a specialized set of educational experiences which are discontinuous from those encountered in everyday life and that it requires and promotes ways of learning and thinking which often run counter to those nurtured in practical daily activities." (p. 553). Research from Greenfield and Bruner (1966), Luria (1971), Cole, Gay, Glick, and Sharp (1971) and others was reviewed to reveal the different skills manifest in classification, reasoning, and concept formation performances when individuals had more schooling experience. First, they noted that schooling contributed to *greater facility in abstract reasoning*. Second, they noted that more schooled individuals were distinguished in their *greater use of language* for describing how they are achieving their tasks, as in memory or classification. These findings included adults as well as children.

Scribner and Cole identified three distinctive features of informal learning:

1. Informal learning is person-oriented, or *particularistic*, in that expectations of performance are based on who a person is instead of what he has accomplished;
2. Informal learning *fosters traditionalism* (since the elders are accorded the highest group status); and
3. Informal learning involves *fusing emotional and intellectual domains*. In informal learning, emotional engagement is wrapped together with cognitive involvement, in part because the content of knowledge is inseparable from the personal identity of the teacher.

Scribner and Cole note that informal learning descriptions by anthropologists also describe common mechanisms, e.g., mimesis, identification, and cooperation (Fortes, 1938; referred to as imitation, identification, and empathy by Mead, 1964). They consider these three categories to be subsumed under a general domain they call "observational learning" – in contrast to learning acquired primarily through language (also see Rogoff, Paradise, Mejia Arauz, Correa-Chavez et al., 2003 for a discussion of an orientation toward learning they call "intent participation," which relies heavily on observation of adult activities).

In contrast to informal learning, formal learning is characterized by: (1) the presence of *universalistic* values, criteria, and standards of performance (over the particularism of who is doing the teaching); (2) *language* is the dominant medium of teaching and learning, rather than the richer sensory context of modeling and observation/imitation common to informal learning; and (3) teaching and learning occur *out of context*, with mathematical symbol manipulation a paradigm case.

Importance of Identity and Broader Units of Analyses

The fusion of emotion/intellectual domains and social/identity issues has been rediscovered in newer work focusing on identity formation in informal learning by youth as it relates to their participation in activities (Holland, Lachiotte, Skinner, & Cain, 1998; Nasir & Saxe, 2003), in larger discourses of disciplines (Gee, 1996), and in issues of affective and motivational issues that underlie and catalyze informal learning (Resnick, 1987; Schauble, et al., 1998).

Later work on informal learning explored additional theoretical constructs that analyzed participation structure in informal learning, and the changing nature of participation in culturally valued activities brought about through such arrangements as *scaffolding* (Wood, Bruner & Ross, 1976; Rogoff, 1990; see Pea, 2004 for history), *apprenticeship* learning (Rogoff, 1990), *legitimate peripheral participation* in "communities of practice" (Lave & Wenger, 1991), and *guided participation* (Rogoff, 2003). A crucial aspect of these approaches is the broadened units of analysis they offer: these views move beyond the study of individuals alone to consider how learning occurs within enduring social groups such as families and communities, and they offer up notions of *cultural practice* and *activity* as fundamental units of analysis (Cole, 1996).

Mutual Influence Perspectives on Development

Ethnographic studies of children in their everyday interactions with others have challenged simplistic socialization accounts of child development that focus on the unidirectional influence of adults on children. Such studies are helping social scientists see the ways that children can propel their own development. From an early age, children often take initiative by asking questions, observing, or taking part in ongoing activities (Rogoff, 2003). Children also contribute creatively to ongoing practices with families and peers by introducing or modifying routines and ways of playing (Goodwin, 1997; Corsaro, 1985), creating new vocabulary and forms of talk (Eckert, 1989), and utilizing the tools of their culture in ways unimagined by prior generations. In turn, parents and other caretakers nurture development not only by providing explanations and role models, but through the manner in which they structure time, introduce topics, purchase toys or other materials, and allow children opportunities to participate in ongoing activities (Ash, 2003; Rogoff, 2003).

The complex intertwining of contributions of both the child and his or her caretakers to cognitive development is nicely exemplified in studies of preschooler's scientific knowledge. Crowley & Jacobs (2002) introduced the idea of "islands of expertise" to reflect the fact that young children often develop considerable knowledge about topics of interest before going to school. They provide the example of a boy who became interested in trains after his parents bought him a book on the topic. This book was read repeatedly and multiple conversations about trains followed, supported by trips to museums and viewing videos. Over time he and his parents built up a great deal of shared vocabulary, schemas for train scenarios, knowledge of mechanisms that allow for train travel, and the like. This shared knowledge in turn allowed the family to have rich conversations that included explanations, elaborations, and analogies to related domains.

Peers are also active learning partners and share knowledge about cultural tools, toys, and practices. For example, children share literature and use it to signify and build friendships (Joiner, 1996) and they share knowledge of how to create and learn with new technologies (Barron, 2004; Chandler-Olcott & Mahar, 2003). With age, children expand their social networks, and peers become more important (Hartup, 1996). Friends, and the parents of friends, may offer a space for activities and conversations not available in their own homes. These studies suggest that we have much to learn about the role of informal learning in the development of interest and knowledge on the road to expertise.

Pathways to Expertise

Many children who fail in school demonstrate sophisticated competence in nonschool activities. In particular, learners from nondominant cultural or lower SES backgrounds appear to learn resourcefully and productively outside of school, even though they may not do well inside school (e.g., McLaughlin, Irby & Langman, 2001). These asymmetries raise important questions about the design of our school systems and what resources allow for success out of school.

The goal of *understanding potential synergies between contexts* is a new area of research that raises questions about how to cross-pollinate learning opportunities across settings. Studies of when, where, and how learning occurs when people make the choice to learn (Barron, 2004; Barron, 2005) suggest we need more sophisticated developmental studies that help us understand pathways to expertise, as they often seem to involve both informal and formal learning opportunities as people move across the multiple life-spaces they inhabit.

Designs for Formal Learning and Beyond

The third research strand illustrated in Figure 2.1 involves using the learning sciences to create learning environments, and studying the effects of these environments to inform theoretical development. Most research in educational psychology falls within this strand. Recently, several research summaries have become available that describe current understanding of how to design effective learning environments.[1] We focus here on the topic of *adaptive expertise*: expert knowledge that supports continual learning, improvisation, and expansion.

Researchers have explored the nature of the skills and knowledge that underlie expert performance (e.g., Ackerman, 2003; Alexander, 2003; Chi, Glaser, & Farr, 1988; Hatano & Osura, 2003; Lajoie, 2003; NRC, 2000a; Rose, 2004; Sternberg, 2003). This research contributes to an understanding of the ways that knowledge, skills, attitudes, and thinking strategies combine to support effective performances in a wide variety of domains.

One important finding is that experts notice features of situations and problems that escape the attention of novices (Chase & Simon, 1973; Chi, Glaser & Rees, 1982). Berliner (1991, 2001) has demonstrated large differences in noticing by novice versus expert teachers that affect their abilities to rapidly identify problems and opportunities and act upon them. Classic work with chess masters was among the first to demonstrate the role of noticing and pattern recognition in expertise (e.g., Chase & Simon, 1973; deGroot, 1965).

The fact that expertise affects noticing has a number of important educational implications. One is that merely showing novice students videos of experts doing things does not guarantee that the novices notice all the relevant features (e.g., Michael, Klee, Bransford, & Warren, 1993). Second, an emphasis on expertise and noticing suggests that we do not simply learn *from* experience; instead, we also learn *to* experience (e.g., Becker, 1953; Goodwin, 1994; Stevens & Hall, 1998).

Research indicates that experts' knowledge is not simply a list of disconnected facts – it is connected and organized around important ideas of their disciplines, and includes information about the appropriate conditions for applying key concepts and procedures. Such information helps experts know when, why, and how aspects of their vast repertoire of knowledge and skills are relevant in any specific situation.

Adaptive Expertise

Recently, research has begun to differentiate "routine expertise" from "adaptive expertise" (e.g., Alexander, 2003; Hatano & Inagaki, 1986; Hatano & Osuro, 2003). Both routine experts and adaptive experts continue to learn throughout their lifetimes. Routine experts develop a core set of competencies that they apply throughout their lives with greater and greater efficiency. In contrast, adaptive experts are much more likely to evolve their core competencies and continually expand the breadth and depth of their expertise as the need arises or as their interests demand. This often requires them to venture into areas where they must function as "intelligent novices" who often struggle initially in order to learn new things (e.g., Brown, Bransford, Ferrara, & Campione, 1983).

Schwartz, Bransford, and Sears (2005) have suggested that the concept of adaptive expertise involves at least two major dimensions; processes that lead to *innovation* or invention and those that lead to *efficiency* through well-practiced routines (Figure 2.2).

Sometimes these two dimensions are characterized as mutually exclusive ends of a continuum (e.g., high and low road transfer, Salomon & Perkins, 1989), yet because there are different processes involved, they are not necessarily exclusive. Adaptive experts are high on both dimensions (e.g., Gentner, Brem, Ferguson, Markman, et al., 1997; Hatano & Inagaki, 1986; Wineburg, 1998). The representation of adaptive expertise in Figure 2.2 suggests how people can develop expertise that engages the strengths of both efficiency and innovation, so they may continually adapt to change.

We suggest the importance of investigating a third dimension that appears to help drive the development of adaptive expertise: a metacognitive awareness of the distinctive roles and trade-offs of the innovation and efficiency dimensions of expertise, and the active design and creative structuring of one's learning environment in order to support their dual utilities. Hargadon and Sutton's work (2000) investigating "innovation factories" in businesses such as the design firm IDEO foregrounds these features of innovation factories, and their successes in developing adaptive business expertise in solving complex design problems may offer fertile insights for new educational designs.

Assessments of Efficiencies Versus Innovation

We are concerned that most of today's assessments tend to be "efficiency" assessments, sensitive to well-learned routines and schema-driven processing but failing to capture innovation or metacognitive awareness. Nearly all standardized tests are "direct application" and "sequestered problem solving assessments" (SPS), where people have access to what is currently in their heads (Bransford & Schwartz, 1999). The expertise literature indicates that well-established routines and schemas are indeed an important characteristic of expertise – freeing up resources of mind and attention otherwise devoted to basic issues (e.g. beginning readers often have such significant problems with decoding fluency that they cannot attend to the meaning of what they read). The ability to directly and efficiently apply previously acquired skills and knowledge is certainly important in many circumstances, as in car driving or plane flying.

One alternative to a direct application view of learning and transfer is a focus on adaptive expertise that has been called "preparation for future learning" (PFL) (Schwartz & Bransford, 1998; Bransford & Schwartz, 1999; Schwartz & Martin, 2004; Martin & Schwartz, 2005; Spiro, Vispoel, Schmitz, Samarapungavan et al., 1987). Here the focus shifts to assessments of a person's abilities to *learn* in knowledge-rich environments. When organizations hire

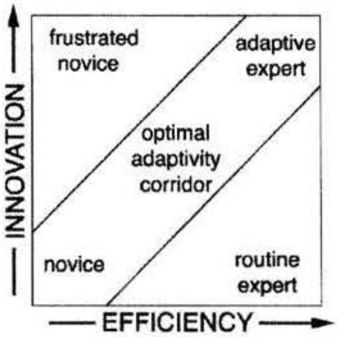

Figure 2.2. Two dimensions of adaptive expertise.

new employees, they want people who can learn, and they expect them to make flexible and competent use of resources to facilitate their learning (e.g. texts, computer programs, social networks of friends, and new colleagues). If people are better prepared for future learning, they will be able to transfer that learning better and faster.

It is important to emphasize that the PFL perspective is different from the *learning-to-learn* literature; the main contrast is that PFL is not principally focused on the existence of a set of general, content-free learning skills. The expertise literature (Chi et al., 1988; NRC, 2000a) shows that strategies and knowledge are highly interdependent; for example, knowing a particular scientific concept can influence the hypotheses that one generates to explain world events. Ideally, assessments of adaptive expertise would include opportunities for people to try out hunches, receive feedback, and attempt to revise based on the feedback. In contrast, typical tests provide few opportunities for feedback and revision – the only option is to provide one's initial thoughts, with no opportunities to test them and revise. Schwartz, Bransford, and Sears (2005) show that assessments of adaptive expertise can reveal the benefits of certain educational experiences, even though those benefits are invisible when standard SPS measures of assessment are used. Many research groups are now exploring innovative ways to measure adaptive expertise (Crawford, Riel & Schlager, 2005; Hatano, 2005; Martin, 2005; Petrosino, 2005; Schwartz, Blair, Davis, Chang et al., 2005; Walker, 2005).

Research on Instructional Strategies for Achieving Adaptive Expertise

The cognitive sciences have principally focused on how routine expertise is acquired, as people get faster and more accurate at solving recurrent problems. Cognitive theories in this tradition emphasize routinized "scripts," "schemas," "frames" and "procedures" (for definitions and examples, see Anderson & Pearson, 1984; Anderson, 1976; Black & Bower, 1980; Bransford & Johnson, 1972; Minsky, 1986; Schank & Abelson, 1977). These functional structures are important for solving problems efficiently. Much instruction in schools guides students to acquire schemas of particular problem types in order to increase problem solving efficiency by turning nonroutine problems into routine problems. An example involves problem types of the form: *"Jim's parents live 60 miles away. He drove to their house at 60 mph and returned at 40 mph due to fog. What was his average speed?"* Most people simply say 50 mph – not realizing that Jim spends a longer amount of time going the slower speed so the average must be less than 50. There are a variety of problems of this type. When people are helped to acquire schemas that allow them to identify particular problem types, they are much less likely to get tripped up when later encountering similar examples. The acquisition of well-organized and easily accessed procedures, scripts, and schemas is extremely important for effective performance – otherwise people are overly challenged by the attentional demands of many components of task performances (e.g., see Bereiter & Scardamalia, 1993). But experts often need to go beyond such schemas, and have to structure experience in new ways. Adaptive expertise allows people to let go of previously acquired knowledge and skills. Efficiency oriented instruction may thus need to be complemented by different kinds of learning activities.

To increase students' adaptive expertise, learning environments should include activities rich with reflection and metacognition that engage them in (1) "knowledge building" rather than merely "knowledge telling" (Bereiter & Scardamalia, 1989, 1993); (2) systematic inquiry with an emphasis on theory building and disconfirmation (e.g., Karmiloff-Smith & Inhelder, 1974/1975; Krajcik & Blumenfeld, this volume) rather than simply following procedures for how to find some result (e.g. NRC, 2005), and (3) designing "working smart" environments that promote innovation in order to increase efficiency (Vye et al., 1998). Students learn about the general goal of efficiently solving a future set of recurring problems, and are encouraged to prepare for such problems by adopting, adapting, and inventing smart tools to help them work more effectively.

Toward a Synergistic Science of Learning

We have discussed three areas of research that seem well positioned for reciprocal influences: (1) implicit learning and the brain; (2) informal learning; (3) designs for formal learning and beyond. Each of these research traditions has operated relatively independently up to this point. We believe that the coming decade holds great potential for achieving a more robust understanding of learning by synthesizing these three traditions. The learning sciences of the future will embody both neural and behavioral aspects of learning, and must account for implicit, informal, and formal learning activities and outcomes. We do not mean that the research strands will merge into one grand theory that eliminates the unique perspectives each offers, but we do believe that these strands can inform one another and, in the process, create more coherent and useful theories that better illuminate why, how, when, where, and what people learn. A major challenge is to articulate problems in ways that will provide the three approaches with the greatest opportunities for convergence. Fortunately, there are several recent advances in our understanding of thinking and learning to build on.

One of the major insights about cognitive performance in the last century is the extent to which the local cognitive and social ecology can constrain or support it (Hutchins, 1995; Pea, 1993; Simon, 1996). This distributed, emergent, and ecological view of cognition has made clear that whereas understanding learners and thinkers as independent and self-contained systems is important, it is not adequate for a robust theory of cognition and learning; we need a better theoretical understanding of the dynamics between people and resources in any learning ecology (Barron, 2004). Conceptualizing learning in ecological terms draws our attention to the multiple interacting aspects of a learning environment: the kinds of learning activities, the material and social resources for learning, the roles that learners take on, the knowledge distributed within social networks, and the practices for exchanging information. The ecological perspective explores the relationships between the person and the environment, and the conditions under which they can exert reciprocal influence.

A second major insight is the importance of social aspects of learning as people engage with learning activities, one another, and their identities as learners and doers of particular activities. Many learning scientists refer to this view as the situative perspective (Greeno, this volume).

A third major insight is the important role of cultural practices for learning, and the understanding that arrangements and values for learning are themselves cultural practices (Cole, 1996; Rogoff; 2003; Nasir, Lee, Roseberry, & Warren, this volume). Too infrequently do school-based learning environments capitalize on diverse ways of learning that have arisen from cultural practices.

Together, these three insights suggest an empirical research agenda that will better position us for developing more comprehensive and practical theories of learning. Below, we highlight three areas rich with opportunities for advancing an interdisciplinary theory of learning through collaboration, synergies, and conceptual collisions:

1. *Moving beyond the individual.* All three perspectives have unique ways of investigating units of analysis comprising systems that transcend the individual. These include pairs, small groups, organizational levels of analysis, and tool-mediated learning at each of these system levels. Families, friendships, peer groups, and larger social networks are all units *of* learning as well as significant contexts *for* learning. Each of the three research strands is investigating the mechanisms and outcomes of learning with others. For example, strand 1 has defined an active program of research to specify how and why social interaction is critical for language learning. Studies of social interaction from a sociocultural perspective follow learners across multiple social contexts – such as family, peers, and mentoring relationships – and pay special attention to how resources for learning are taken up, including material resources such as books or computers, but also attitudes and practices surrounding learning. Design-oriented cognitive psychologists are working to specify features of tasks that make it more likely for people to engage in the kinds of interactions that will lead to learning, a topic we know a good deal about from studies of collaboration.
2. *The role of affect in learning.* Though informational resources are important in any learning ecology, affective and motivational resources are also important because they may mediate effort, attention, and a desire to engage in learning. We need a better understanding of the intertwining of affective, relational, and communicative aspects of learning interactions. How do emotional responses mediate learning, and how do they emerge from learning? Research from within strand 1 is beginning to study the brains of adults as they interact, and has located distinct regions associated with competitive versus cooperative activity (Decety, Jackson, Sommerville, Chaminade, et al., 2004). Strand 2 work documents the complex processes of learning in longstanding relationships, and the ways that interactions between people are central for understanding the successful building of collective knowledge or failed attempts at joint work (Barron, 2003). Strand 3 designs experiments to specify the mechanisms underlying persistence and withdrawal of efforts. These areas of investigation can contribute to a better understanding of people's life choices with respect to academic pathways.
3. *Expanding our conception of what is learned.* Most studies of learning have focused on academic content. However, as studies of cognition in action tell us, there is more to expertise than content knowledge. The notion of adaptive expertise reflects this broader conceptualization and raises more questions. Do people learn to interact in more and less productive ways for doing collective work, and does that then change their capacity for learning through collaboration? The area of metacognition is also ripe for expansion – for example, do people become better able to reflect on complex social interactions and recognize when crucial aspects of joint work are not functioning well (such as joint attention or differences uses of terms)? Some have referred to this kind of perception as "professional vision" (Goodwin, 1994; Stevens & Hall, 1998), and define it as being able to see the categories that matter in a community of practice. Recent work on complex organizations also suggests that some environments are better designed for learning and innovation than others (Hargadon & Sutton, 2000). How is it that people become sensitive to their environment, and how do they learn to arrange things for maximum well-being, productivity, and innovation? How do they appropriate and invent new practices of learning? All three strands pursue these kinds of questions and have unique tools for investigating them.

In closing, the ecological, situative, and increasingly cultural approaches characteristic of the learning sciences can help us to understand the biological and embodied aspects of learning and development that shape adaptation. The developmental neuroscience community is helping to articulate how the brain develops in continual interaction with the environment, and how the developing brain influences how later environments are perceived. As a National Academy of Science report (NRC 2000b) suggested, we need a science of learning that works from "Neurons to Neighborhoods."

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Footnote

1. These reports include *How People Learn* (NRC, 2000a), *Knowing What Students Know* (NRC, 2001), *Learning and Understanding* (NRC, 2002), *Learning and Instruction: A SERP Research Agenda* (NRC, 2003), *Internet Environments for Science Education* (Linn, Davis, & Bell, 2004), *How Students Learn* (NRC, 2005), and *Preparing Teachers for a Changing World* (Darling-Hammond & Bransford, 2005).

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