Scientific Antecedents of Situated Cognition

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Introduction

In the late 1980s, an artificial intelligence (AI) researcher trying to untangle controversy about the nature of knowledge, memory, and behavior would be surrounded by perplexed computer science and psychology colleagues, who viewed situated cognition ideas as "fools gold" or even suggested that it threatened the foundations of science itself. But a scholar would know the concepts and methods of situated cognition within a much broader and deeper background, one that embraced Dewey's (1896) early objections to stimulus-response theory, Wittgenstein's (1953) notion of family resemblances and the language game, Gibson's (1966) affordances, Bateson's (1972) ecology of mind, Polanyi's (1966) tacit knowledge, von Bertalanffy's (1968) general systems theory, and so on, in the work of dozens of well-known figures in philosophy, psychology, linguistics, ethology, biology, and anthropology. Indeed, throughout science, including artificial intelligence itself during the 1960s and 70s, one finds at least the seeds for a "situated" theory of cognition. This chapter provides a broad historical review of the scientific antecedents of situated cognition[1]; philosophical aspects are detailed by Gallagher (this volume).

What idea could be so general that it applies to every scientific discipline? And why was this idea so controversial within the AI community? What aspect of cognition relates the social sciences, linguistics, pedagogy, animal cognition, and evolutionary biology to neural theories of perception, learning, and memory? What problematic aspects of cognition within AI research foreshadowed the development of a "situated"

[1] This is a story about the conceptual foundations of situated cognition; see Sawyer and Greeno (this volume) for how the particular theories of situativity and learning in the 1980s and 1990s developed.

epistemology? These are the topics I discuss in this chapter. In large part, the story centers on particular scientists, but I present the central ideas as cross-cutting themes. These themes reveal that human cognitive processes are inherently social, interactive, personal, biological, and neurological, which is to say that a variety of systems develop and are dependent on each other in complex ways. Many stories could be told about these interrelations. The concepts, perspectives, and theoretical frameworks that influenced the situated cognition of the 1980s are still alive in potential for thoughtful reconsideration in tomorrow's cognitive research.

The key concept across the sciences that in the realm of AI and cognitive science was manifested as "situated cognition" is today often called *systems thinking* (von Bertalanffy, 1968). This idea is manifested in different forms as general systems theory, complex systems (simply "complexity"; Waldrop, 1992; Gell-Mann, 1995), system dynamics, chaos theory (Prigogine, 1984; Gleick, 1987), complex adaptive systems (Holland, 1996), and so on. These are modeling approaches with a broadly shared perspective concerning how causality operates within many natural and some designed systems (Altman and Rogoff, 1987). For example, systems thinking views human expertise as occurring within and developing *as a system*, involving an economic market, a community of practice, facilities, representational tools, reasoning, and perceptual-motor coordination. (Lave, 1988).

The following major section provides an introduction to systems thinking and its application in systems theory. This is followed by a review of the historical context in which a non-systems thinking perspective developed in the study of intelligence, particularly AI research. I then briefly review how systems thinking relates to and is manifest in the study of cognition. The core of this chapter then summarizes cross-cutting themes, constituting the scientific antecedents of situated cognition. Finally, I consider recent and continuing dilemmas that foreshadowed the acceptance of situated cognition within AI and psychology and suggest prospects for the next scientific advances.

Systems Thinking Overview

Systems thinking[2] involves studying things in a holistic way—understanding the causal dependencies and emergent processes among the elements that comprise the whole system, whether it be artificial (such as a computer program), naturally occurring (such as living systems), cultural, conceptual, etc. A *system* is viewed as a dynamic and complex whole, an organization (e.g., a cell, a community) located within an environment. We look at the inputs, processes, outputs, feedback, and controls, to identify bidirectional relationships that affect and constitute a system.

In identifying parts and wholes, systems thinking doesn't reject the value of reductionist compartmentalization and componential analysis; rather one strives for a "both-and" perspective (Wilden, 1987) that shows how the whole makes the parts what they are and vice versa. For example, in conceptual systems metonymic relations (tropes, also called "figures of speech") may have a "both-and" meaning. Consider how the Sydney Opera House, derided at first as "a pack of French nuns playing football" (Godwin, 1988, p. 75) became a symbol for Australia—and thus changed the national identity, what "Australia" meant to the Australians and the world. The radical and captivating architecture, built for a high cultural purpose, marked Australia as a modern,

[2] Definitions in this section are adapted from the Wikipedia discussion: http://en.wikipedia.org/wiki/Systems_Thinking, retrieved June 7, 2005. See also New England Complex Systems Institute for an introduction (NECSI, n.d.).

preeminent society, occupying a unique position within the world (like the building on harbor's edge) and a force for change. Thus, the meaning of the nation (the whole) and the meaning of the building (a part) reaffirmed each other. The building is *both* contained in the country *and* a symbol for the country as a whole.

In situated cognition one of the fundamental concepts is that cognitive processes are causally both social and neural. A person is obviously part of society, but causal affects in learning processes may be understood as bi-directional (Roschelle and Clancey, 1992).

Systems thinking also views "the parts" from different disciplinary viewpoints. For example, in building a highway, one could consider it within a broader transportation system, an economic system, a city and regional plan, the environmental ecology, etc. (Schön, 1987). Thus "the design" of the highway system would be framed by different categories and relations from different viewpoints, producing different ontologies of parts and causal processes; the constraints between these perspectives are the basis for defining trade-offs for costs and benefits.

Such a multidisciplinary view of problem-solving both extends and challenges the disciplinary notion of expertise that assumed an objective ontology ("truth about the world"), which was inherent in most "knowledge acquisition" theories and methods (Hayes-Roth, Lenat, and Waterman, 1983). For example, in the 1970s it was common to build a medical expert system for a clinic by working only with physicians in a particular subject area, omitting the nurses, hospital managers, computer system administrators, insurance companies, family doctors, etc.

Adopting a systems perspective, new insights may be gained into what problems actually occur in a given setting and why, what opportunities technology may offer, and how changes in tools, processes, roles, and facilities may interact in unexpected ways (Greenbaum and Kyng, 1991). These ideas were becoming current in business management (e.g., Senge, 1990; Jaworski and Flowers, 1996), just as situated cognition came on the scene in AI and cognitive science.

Systems theory

Systems theory[3] is an application of systems thinking, closely related to cybernetics (Wiener, 1948) and what is now called *complex systems*. Systems theory was founded by von Bertalanffy (1968), Ashby, and others between the 1940s and the 1970s on principles from physics, biology and engineering. Systems theory was especially influential in social and behavioral sciences, including organizational theory, family psychotherapy, and economics. Systems theory emphasizes dynamics involving circular, interdependent, and sometimes time-delayed relationships.

Early systems theorists aimed for a *general systems theory* that could explain all systems in all fields of science. Wolfram (2002) argues that a computational approach based on cellular automata begins to provide an appropriate formulation of systemic structures and processes. Ironically, computer scientists and psychologists who found situated cognition perplexing around 1990 did not recognize its roots in the work of von Neumann and Burks (1966), cybernetics (von Foerster, 1970), or parallel developments in *general semantics* (Korzybski, 1934). Each of these theoretical developments

[3] Definitions in this section are adapted from the Wikipedia discussion: http://en.wikipedia.org/wiki/Systems_theory, retrieved June 7, 2005.

contradicted the tenets of "knowledge base" theories of intelligence (Clancey, 1997). These tenets include: a temporally linear process model relating perception, conception, and action; stored propositional memory; identification of scientific models and knowledge; single-disciplinary view of problem formulation.

In contrast, the development of connectionism in AI (McClelland, Rumelhart, and the PDP Research Group, 1986) promoted theories and models characterized as *complex adaptive systems* (Holland, 1996; Gell-Mann, 1995; Harold Morowitz, van Gelder, 1991). This distributed processing, emergent organization approach is also manifest in *multi-agent systems modeling*, which brings the ideas of cellular automata and systems theory back to the computational modeling of human behavior (Hewitt, 1977; Clancey, et al., 1998).

Features of complex systems

Within systems theory, the term *complex system*[4] (Gallagher and Appenzeller, 1999; Waldrop, 1992; CSCS, n.d., NECSI, n.d.) refers to a system whose properties are not fully explained by linear interactions of component parts. Although this idea was well known to many AI scientists by the mid-1980s in technical areas called *artificial life* and *genetic algorithms*, its applicability to the study of cognition proper (such as the nature of conceptual systems or how memory directly relates perception and action) was not generally recognized. In particular, applications to education ("situated learning," Lave and Wenger, 1991) and expert system design ("communities of practice," Wenger, 1998)

[4] Definitions in this section are adapted from the Wikipedia discussion: http://en.wikipedia.org/wiki/Complex_system, retrieved June 7, 2005.

were difficult for proponents to articulate—and for others to understand—because the epistemological foundation of knowledge-based systems was at question.

The following features of complex systems are useful to consider when analyzing human behavior, a social system, an organizational design, etc.:

Emergence: In a complex system (vs. a complicated one) some behaviors and patterns result from interactions between the elements, and the effects are non-linear.

Feedback loops: Both negative (damping) and positive (amplifying) feedback relations are found in complex systems. For example, in cognition causal couplings occur subconsciously within processes of conceptualization and perception, consciously as the person reflects on alternative interpretations and actions, and serially as the physical world and other people are changed by and respond to the person's action. Situated cognition reveals non-conceptual and non-linguistic aspects of these feedback relations, while highlighting conceptual aspects pertaining to identity and hence social relations.

Open, observer-defined boundaries: What constitutes "the system" being studied depends on questions at issue and purposes for knowing. For example, is the boundary of a person his or her body? Are clothes part of the person? If you stand uncomfortably close to someone, have you crossed an emotional boundary?

Complex systems have a history: How the parts have interacted in the past has changed the parts and what constitutes their system environment (i.e., "the response function depends on a history of transactions," Shaw & Todd, 1980).

Compositional networks: The components of the system are often themselves complex adaptive systems. For example, an economy is made up of organizations, which are made up of people, etc.

Historical Context of the Stored Program Theory of Mind

Having now presented the seeds of the reformation—systems thinking and complex systems—we now return to the context of the reactionary—the cognitive theories that conflict with situated cognition. This brief synopsis provides background for recognizing the novelty and usefulness of the cross-cutting themes of sociology, language, biology, etc. presented subsequently.

First, one must recognize that the founders of AI in the 1950s were themselves reforming psychology and even the nature of science. Newell and Simon (1972) explicitly contrast their reductionist process theory with behaviorism (p. 9), which sought to explain behavior without reference to unobservable internal states. Minsky (1985) refers to gestalt theories as halting analysis of cognition into interacting components. Thus, the founders of AI were biased to view cognition as fully explained by inputs and internal processes that could be broken into structure-states and functional transformations. Consequently, situated cognition claims that aspects of "the mechanism" of cognition were outside the head could be interpreted as a fruitless return to "the great debates about the empty organism, behaviorism, intervening variables, and hypothetical constructs" (Newell and Simon, 1972, p. 9-10; cf. Vera and Simon, 1993).

AI research was strongly shaped by the stored computer "von Neumann" metaphor, which included formal machine theory (e.g., automata and formal languages), separation of short-term memory (registers) and stored program, functional specifications relating inputs and outputs. The derivative information processing metaphor of the mind tended to equate data and information, knowledge with models, intelligence with verbal-logical reasoning, human activity with tasks, and goals with problems to be solved (Clancey, 1997; 2002).

The success of the computational metaphor led to the view that a cognitive theory is not well-formed or useful unless it is implemented as a computer program (Vera and Simon, 1993): "the model captures the theory-relevant properties of a domain of study" (Kosslyn, 1980, p. 119). Thus in the study of intelligence, most researchers assumed that having a useful, functional understanding (i.e., knowledge) required a model (derived from theoretical understanding). Questioning this relation threatened the notion that progress in psychology (and hence AI) depended on explicating knowledge as propositions, rules, and functional procedures (e.g., the idea that common sense knowledge should be exhaustively captured in a knowledge base; Lenat and Guha, 1990).

During the three decades starting with the mid-1950s, AI was largely separated from sociology and anthropology, and the seeds of situated cognition in ethology were largely ignored[5]. During this time, the knowledge-based paradigm took hold, and AI research shifted dramatically from "blocks world" games to specialized expertise of professionals in medicine, science, and engineering. With the focus on individual experts (reinforced by the professional view of textbook knowledge; Schon, 1987), the idea of "distributed cognition" was not in vogue until the late 1980s, and culture was viewed, if it was considered at all, as a collection of common knowledge (vs. a complex system of diverse artifacts, skills, and practices; Lave, 1988).

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[5] As a graduate student in the 1970s, I read a *Natural History* article about the dance of the bees and wondered, how did insect navigation relate to expert reasoning? Could we model the bee's knowledge as rules? Brooks (1991) provided an alternative theory.

In trying to identify "the" internal structures that caused intelligent behavior, AI was philosophically grounded in objectivism (e.g., universal ontologies, scientifically defined). Failing to recognize different disciplinary frameworks for modeling reality for different purposes (e.g., the road design example cited above), AI explicitly embraced a reductionist theory of knowledge consisting of enumerable discrete elements (e.g., propositions, terms, relations, procedures). The folk distinction between skills and factual knowledge was well known, but the computational metaphor suggested that skills were simply compiled from previously known facts and rules (e.g., Anderson, 1983), which reinforced the stored-program memory metaphor. Systems thinking may have seemed incompatible or irrelevant to AI researchers because it threatened the grammar-based theories (e.g., see Winston and Shellard, 1990) that had been so successful in understanding aspects of speech recognition, text comprehension, scene and object recognition, and problem solving.

As in other fields, the seeds of situated cognition were probably always present in the AI community. Connectionism might be viewed as the clearest outgrowth of systems thinking in AI, suggesting a theory of memory compatible with situated cognition (e.g., Clancey, 1997, pp. 69 ff, Chapters 4 and 7; Clancey, 1999). Connectionism has direct origins in early neural network modeling (e.g., the work of Warren McCulloch) that inspired the founders of AI. Indeed, by 1950 Minsky began developing "a multiagent learning machine" (Minsky, 1985, p. 323). However, "low-level distributed-connection learning machines" were too limited (Papert and Minsky, 1969), so Minsky focused instead on common sense reasoning. Minsky (1998) expressed this continuing theoretical concern with examples such as knowing that "You can push things with a straight stick but not pull them."

Minsky's (1985) encompassing *Society of Mind* combined the original notion of a network of agents with nearly three decades of work on vision and simple problem solving, arguing (in the words of Winston and Shellard [1990, p. 244]) that intelligence emerges from contributions of a heterogeneous organization of agents. *Society of Mind* does not mention systems theory, but does credit cybernetics with enabling the concept of "goal" to be used in psychology (p. 318). Minsky includes internal regulation and feedback in his framework, clearly based on biological theory.

But like Newell and Simon (1972), having conceived cognitivism as anti-behaviorist, Minsky (1985) had difficulty relating his theories of agent interaction to systems thinking. He stated that emergence was a "pseudo-explanation," merely labeling phenomenon that could be explained by taking into account the interactions of parts (p. 328). In defining "gestalt" for example, he says that "'holistic' views tend to become scientific handicaps," and that "there do not appear to be any important principles common to the phenomena that have been considered, from time to time, to be 'emergent.'" (p. 328). On the one hand, Minsky was right to press for the study of parts and interactions, but he appeared to deny the distinction between complex and complicated systems.

In contrast, at this time Papert, Minsky's *Perceptrons* collaborator, pursued systems thinking ideas in the realm of education, building on Piaget to explicitly teach "administrative ways to use what one already knows" (Minsky, 1985, p. 102), which Papert realized as a form of *constructivism* (see below).

Also at the same time, Hewitt, a student of Minsky, had promoted a de-centralized procedural model of knowledge (Hewitt, 1977). His ideas were picked up in the "blackboard architecture" of AI programs, which harkened back to 1940s neurobiological models. The blackboard approach was successful in the 1970s because it provided an efficient functional decomposition of a complex process: Heterogeneous "knowledge sources" (also called actors, beings, demons) operate in parallel to access and modify a symbolic construction (e.g., an interpretation of a speech utterance) represented at different levels of abstraction (e.g., phonemes, words). The relation of this computational architecture to complex, open systems in nature and society was not generally acknowledged until the 1990s (but see Hewitt, 1985)[6].

We must recognize that every field has its own controversies and antinomies, with some individuals questioning what the majority of their colleagues take for granted. Even for well-established areas of study, the book is never entirely closed. For example, Kamin's (1969) research on simple animal cognition questioned whether even classical conditioning could be explained without delving into cognitive theory. *Society of Mind* is indeed a broad exploration that goes well beyond what could be implemented in a computer model when it was formalized in the decade around 1980. The formation of the Cognitive Science Society in 1980 could itself be viewed as a recognition of the need to regroup and identify the perspectives that needed to be reconciled. Nevertheless, the strong reaction to situated cognition research in the decade around 1990 demonstrates that something new and conceptually difficult to assimilate was being introduced. The

[6] As evidence for the fragmentation of ideas within AI, note that Minsky (1985) does not cite Hewitt's "actors" model.

next section outlines the leap to systems thinking that understanding situated cognition requires.

Manifestation of Systems Thinking in Situated Cognition

For a psychologist in particular, systems thinking reveals contextual effects that cannot be viewed simply as "environmental" or "input." Thus one studies authentic, naturally occurring behaviors, with the awareness that inputs and outputs defined by an experimenter (e.g., lists of words to be sorted) may set up situations unrelated to the person's problematic situations and problem-solving methods in practice (Lave, 1988). In particular, determining what constitutes information ("the difference that makes a difference" [Bateson, 1972]) is part of the cognitive process itself (vs. being predefined by the experimenter), and often involves a causal feedback with physical transformations of materials, such that looking, perceiving, conceiving, reasoning, and changing the world are in dynamic relation (Dewey, 1938).

One way of understanding a dynamic process is that the system that is operating—the processes being studied, modeled, controlled, and/or designed—cannot be understood in their development or function as strictly localized within one "level" of analysis (e.g., see Gould, 1987). That is, cognitive processes are not strictly attributable (reducible) to neurological mechanisms, nor are they purely conceptual (e.g., driven by knowledge), characteristics of a person, or properties of the physical world. But rather, what is *experienced* by a person and viewed by an observer—of organisms, mental performance, individuals, organizations, populations, ecologies, etc.—is the ongoing product of a *coupled* causal relation, such that the entity being studied and its context (whether neurological, conceptual, physical-artifactual, interpersonal, or ecological) are shaping each other in a complex system. Thus, scientific insights of systems thinking (read “situated thinking”) in areas of study ranging from neurology to environmentalism are often framed as *blended disciplines*: Genetic Epistemology, the Biology of Cognition, the Sociology of Knowledge, Neuropsychology, Evolutionary Biology, Social Cognition, etc.

Claims, Challenges, and Contributions

In summary, “situated” can be understood as emphasizing the contextual, dynamic, systemic, non-localized aspects of the mind, mental operations, identity, organizational behavior, and so on. Across the sciences of psychology, anthropology, sociology, ethology, biology and neurology, and their specialized investigations of knowledge, language, and learning, the systemic, holistic view strives to explain behavior within a developmental and evolutionary framework. Specifically, in situated cognition human knowledge is viewed not as final objective facts, but as 1) arising conceptually (dynamically constructed, remembered, reinterpreted, etc.) and articulated within a social context (i.e., a context conceived with respect to social roles and norms), 2) varying within a population in specialized niches (areas of expertise), 3) socially reproduced (e.g., learning in communities of practice; Lave and Wenger, 1991), and 4) transformed by individuals and groups in processes of assimilation that are inevitably adapted and interpreted from unique perspectives (improvised in action, not simply transferred and applied).

Articulating the “situated” view of knowledge has been and remains difficult because to some people it has suggested cultural relativism of science (Slezak, 1989; Bruner, 1990, p. 27). Indeed, the debate appears on the public scene in the issue of how

US Supreme Court judges are to interpret the US Constitution[7]. But ironically, fears of arbitrariness (stemming from the view that if an understanding is not objective it must be arbitrary) assume that either scientific or legal activities might occur in a vacuum, apart from a complex system of social-historical-physical constraints—as if, for example, a science that ignored physical realities of how sensors operate could accomplish anything at all, or that checks and balances in the legal system would allow a judge's ruling that ignored precedent to stand. Wilden (1987) refers to these confused debates (e.g., objective vs. arbitrary) as "a switch between imaginary opposites" (p. 125). Thus, some objections to situated cognition arose because of a reactionary concern that open systems could be arbitrary, and that control must be imposed "from outside" to keep complex systems organized (see Lakoff's [2002] analysis of political metaphors; Clancey, 2005).

In summary, situated cognition developed, not as a discipline (or a movement) within AI or psychology or educational technology, but as a way of thinking proclaimed by some of the most well-known scientists of the 20th century in psychology, biology, ethology, sociology, psychiatry, and philosophy. Granting that the threads of the argument were known since Dewey (1896) at least, what did the proponents of situated cognition of the 1980s and 1990s add to our understanding of systems, causality, and mental operations? The contributions include:

- Better scientific models and modeling techniques (e.g., models of memory and learning, such as Edelman's [1987] neuronal group selection).

[7] For a discussion of the dichotomy between the "living constitution" (arbitrariness) and strict interpretation (objectivity)—indeed an argument against either-or thinking—see Scalia's remarks at the Woodrow Wilson International Center for Scholars in Washington, D.C., on March 14, 2005, available at: http://www.cfif.org/htdocs/freedomline/current/guest_commentary/scalia-constitutional-speech.htm

- Beginning to relate explanatory models on different levels (e.g., "symbolic" and neural models; Clancey, 1999).
- Improved theories and practices in learning and instruction (e.g., Koschmann, in preparation), as well as software engineering (e.g., Greenbaum and Kyng, 1991; Clancey, 2006), arising through extensive multidisciplinary collaborations between social and computer scientists.
- The extension of cognitive theory beyond games and expert problem solving to include the nature of consciousness and emotion (e.g., autism, dreaming, and dysfunctions).

But perhaps most visibly and germane to the original objectives of AI, "situated robotics" flourished as dynamic cognition theories based on feedback, interaction, and emergence inspired new approaches to navigation, perceptual categorization, and language learning (Clancey, 1997, Chapter 5).

Disciplinary Perspectives

In relating cognitive studies to other sciences, it is apparent that no single discipline has all the answers. All have had parallel developments that were contrary to situated cognition and even within their own discipline viewed as lacking an appropriate contextual aspect. For example, some anthropologists might be critical of *ethnoscience* (a development within cognitive anthropology), because the study of how people perceive their environment through their use of language may use phonemic analysis too narrowly, reifying linguistic categories as if they have a reality apart from their existence within conceptual and cultural systems.

Arguably, epistemology underlies all of situated cognition, and thus one might say that all cognitive research in sociology, anthropology, education, psychology, and even neurology is aimed at developing an appropriate epistemology and articulating its manifestations in different settings. From a psychological perspective, the fundamental issues often boil down to how we should properly relate memory, perception, problem solving, and learning. For many AI researchers and cognitive psychologists, such a theory must be inherently expressed as a mechanism, in particular a computer program that implements the theory of memory and mental processing. But systems thinkers argued that cognitive processes are not like conventional computer programs. Wilden (1987), a communication theorist, contrasted a "mechanism" (meaning something like a clock made of gears, a machine-ism) with an "organicism" (essentially an open system). Further, Bateson (1972), an anthropologist-philosopher, argued whether "mental" was a phenomenon that could be localized as a process inside the brain (as opposed to being a person-environment interactive process).

Telling this multidimensional, historical development is challenging, for it was never known to anyone at any time in all of its threads and perspectives. Nor, because of its complex form can we find a viewpoint for grasping it, as it were a landscape, from a single, all-encompassing perspective. Post-hoc we can trace themes, such as epistemology and the theory of memory, making causal links between individuals, publications, institutions, and even pivotal academic meetings. Even a litany of concepts or issues is perspectival, articulated, and exploited within a particular community's interests and problems. It helps to recognize the many dimensions of analysis at play, and to attempt to identify issues that pertain to different concerns:

- **Academic Disciplines**: Philosophy, psychology, sociology, education, management, anthropology, biology, computer science, neural science, etc.
- **Cross-Disciplines:** Philosophy of Mind/Science, Cybernetics, Social Psychology, Cognitive Anthropology, Cognitive Science, Artificial Intelligence, Neuropsychology, Evolutionary/Genetic Epistemology, Evolutionary Biology, etc.
- **Applications:** Robotics, Instruction/Training, Process Control Automation, etc.
- **Methodologies:** Socio-Technical Systems, Ethnomethodology, Knowledge Acquisition, Cognitive Task Analysis, etc.
- **Modeling/Representational Frameworks:** Theory of computation, cybernetics, semantic networks, heuristic classification, qualitative causal modeling, neural networks (connectionist models), genetic programming, etc.
- **Cognitive Functions**: Representation – Memory – Knowledge – Learning
- **Cognitive Elements:** percepts, concepts, relations, procedures, beliefs, goals, desires, theories, activities, motives, skills, etc.
- **Cognitive Behavior:** Language, Classification, Problem Solving, Navigation, etc.
- **Systemic Concepts**: Dynamic, feedback, self-regulation, emergence, chaos, interactionism, constructivism, contextualism, ecology, ethnomethodology, self/identity, etc.

In teaching a course about situated cognition from a historical perspective, the pivotal scientific areas of study are the nature of *learning* (as social, psychological, neurological, etc.), *animal cognition*, and *neurology* (i.e., how the brain accomplishes cognitive functions). Indeed, although "symbolic" AI and problem-solving research in cognitive science fell behind the systems thinking developed in other sciences in the 1970s, it is apparent that systems thinking itself was changing dramatically, as it was rearticulated in a communication theory that combined physics and philosophy by cyberneticists (von Foerster, 1970, 2003), and then developed into chaos and complexity theory in the 1980s (Prigogine, 1984; Waldrop, 1992) and into what Wolfram (2002) calls "a new kind of science" based on cellular automata (pp. 12-14).

Is it a coincidence that the term "situated learning" was introduced in the 1980s not long after "animal cognition" became a mainstream topic for ethology, or at the same time the neural sciences adapted a AI computational modeling method to formulate the theory of connectionism? Strikingly, each 1980s thread relating to learning, animal cognition, and neurology was firmly grounded in well-known (including Nobel Prize winning) research 40 to 100 years earlier. Indeed, one would have to view the development of scientific ideas relating to situated cognition as a complex system itself—non-linear, historical, emergent, nested, networked, with open boundaries and feedback loops, etc.

In particular, and crucially, no discipline of focus of study is more fundamental or "inside" another: A computational theory will not "explain" psychology any more than situated learning could explain culture. Also, insights do not accumulate monotonically; insights from Dewey or 1950s cybernetics might be stomped on by today's communication theory (Radford, 1994).

Not only the history of situated cognition, but the systems comprising cognition are in principle complexly related. Physiological, conceptual, and organizational systems are mutually constraining—not causally nested—in what Wilden (1987, p. 74) calls a *dependent hierarchy* of environmental contexts. Culture is the most diverse and complex system, but lies at the bottom of the dependent hierarchy. Like any open system, culture depends for its existence on the systems that contain it environmentally—society, organic (biological), and inorganic nature (at the top). Diversity and complexity increase on descending the dependent hierarchy; constraints become more general on ascending. An individual organism is a complex of the two higher-orders of complexity (organic plus inorganic), and "a person…is a complex of 'both-and' relationships between all four orders of complexity" (culture, society, organic, and inorganic), so cannot be logically fitted within this hierarchy (p. 74).

At best, in writing a scientific history one can hope to mention most of the names and ideas that other stakeholders (researchers in education, psychology, anthropology, etc.) would cite, providing not as much a chronological tale, but a coherent relation of people and concepts that fit to tell a coherent, useful story. Especially, the best motivation might be the question, "What should any student know about the work that came before, particularly, what might be fruitfully read again, in the original, for inspiration?" This is my criterion for selecting the scientific ideas that follow, emphasizing primary sources that future researchers should read and interpret for themselves.

Cross-Cutting Themes of Cognition

I organize scientific work related to situated cognition according to what discipline or field of study the advocates were grounded in—Philosophy, Education, Sociology, Language, Biology, Neurology, Anthropology—and then group related work by themes that were developed by studying cognition from the given perspective. This is different from a "cognitive element" perspective, insofar as research on memory for example appears both in the Language plus Cognition category as well as Neurology plus Cognition. My aim is to show fundamental relations between ideas, not what aspects of mind were derived from the studies. The themes are research topics embodying a situated perspective. Space allows only a brief mention of each person's work; for elaboration please see the references cited.

Constructivism$_1$: Philosophy + Cognition

Constructivism is a theory of learning that people create knowledge from the interaction between their existing knowledge or beliefs and the new ideas or situations they encounter.[8] Constructivist pedagogy tends to stress the importance of both teacher/environmental guidance and learner activity. One thread of constructivist thinking developed in the philosophy of psychology, in the late 19th century American pragmatism (Konvitz and Kennedy, 1960) of Charles Pierce, William James, and John Dewey; see Gallagher, this volume). This perspective emphasized that knowledge was not merely transferred, but a transformation developed within and through the person's action. Most simply, this means that people can be instructed and are not simply learning habits (rote learning). Importantly, "being instructed" means that what is learned is subjectively interpreted and assimilated. The subjective aspect emphasizes both that knowledge can not be identified with the curriculum (which Dewey [1902] called a map for learning) and

[8] "constructivism." *Webster's Third New International Dictionary, Unabridged*. Merriam-Webster, 2002. http://unabridged.merriam-webster.com (26 Jul. 2005).

that the learner is consciously reflecting on and making sense of instructive situations and materials in actively looking and touching while doing things. Two constructivist principles suggested by Glasersfeld (1984, 1989) build on Piaget's work and philosophical realism (e.g., Vico and Berkeley): "a) knowledge is not passively received but actively built up by the cognizing subject; (b) the function of cognition is adaptive and serves the organization of the experiential world, not the discovery of ontological reality."

Constructivism$_2$: Education + Cognition

Constructivist epistemology combined with developmental psychology to greatly influence pedagogical designs in the 20th century (Dewey, 1902; 1934; 1938; Piaget, 1932; 1970a; b). Research emphasizes the development of individuals, to understand the learner's active cognitive operations (e.g., Dewey's [1938] notion of "inquiry") strategies, stages of conceptual development, the nature of experiential processes of assimilation and accommodation. Learning interactions can be analyzed from many dimensions, including perception, conception, representation, skills, actions, material interaction and transformation (i.e., interpreting instructions; arranging objects into a design). Perception-conception and action are understood to be mutually interacting (which Dewey [1896] called "coordination").

Constructivism$_3$: Sociology + Cognition

More broadly, a social perspective emphasizes that the environment includes (often physically, but always conceptually) other people with which the learner participates in activity systems (Leont'ev, 1979; Vygotsky, 1978; Wertsch, 1979; 1985;

1991). The individual and society are mutually interacting: "culture…is the capacity for constantly expanding the range and accuracy of one's perception of meanings" (Dewey 1916). A social-cognitive analysis emphasizes: interpersonal communication, mutual-dependent action in a group (e.g., as in playing hide and seek), action by a group (e.g., involving specialized and coordinate roles, as in a team playing soccer), and identity (the conscious concept of self as a person engaging in normative, participatory activity).

This system in which learning occurs is described by Dewey and Bentley (1949) as "transactional," emphasizing mutual, historical development across levels, between individuals, and through comprehending and doing (Clancey, in preparation). Cole (1996) and Cole and Wertsch (1996) emphasize this co-construction aspect: Both the child and the environment are active, and culture is "the medium within which the two active parties to development interact."

Both the social and perceptual-motor coordination perspectives suggest that the phenomenon of *knowing* (or mind) cannot be localized as a system existing wholly within a person's brain. As explained, this was seriously at odds with arguments against behaviorism and gestalt theory, and thus appeared to turn away again from decomposing the brain's structures and processes. Constructivism was not denying the role of the brain, but emphasizing that it was not the locus of control in determining behavior—nor was the individual the locus of control; and in no case was human behavior simply a linear process of logical transformation from stimulus to decision to action.

Although not often cited in situated cognition research by psychologists, Mead (1934), a sociologist, developed a theory of the emergence of mind and self out of the social process of significant communication, which become the foundation of the symbolic-interactionist school of sociology and social psychology (Cronk, 2005). *Symbolic interaction* focuses on the construction of personal identity through interactions of individuals, especially through linguistic communication ("symbolic interaction"). Meanings are thus socially constructed and interrelate with actions. Other noted symbolic interactionists are Herbert Blumer and Goffman (1959). Polanyi (1966) developed these anti-positivist theories further in his elucidation of the nature of tacit knowledge.

By the 1970s, sociology ideas stemming from turn of the century were reformulated in the sociology of knowledge (Berger and Luckhman, 1966), a constructivist theory that emphasized the learning of individuals in their social lives, as actively making sense of and thus forming a social reality (e.g., Shibutani, 1966). The anthropologist Hall's *The Silent Language* (1959) provides a virtuoso exposition of the nature of culture, in a theory of communication that relates formal, informal (e.g., spatial-temporal layout, gestures), and technical conceptual systems. Latour (1999) has applied the social construction perspective to science itself, leading to the side debate that situated cognition was undermining the integrity of science (Slezak, 1989). Stemming from the early work by Durkheim (1912), the philosophy of science here intersects with the epistemological study of common sense, namely that scientists and ordinary folk are using different tools for developing theories of their world, but still constrained by (and actively changing) a social-historical environment of language, instruments, and values.

Remembering, Story-Telling, Theorizing: Language + Cognition

Philosophy, pedagogy, and sociology defined broad constraints for a "complex system theory of mind," but it remained for more specific studies of cognitive processes to elucidate what and how processes were distributed and temporally developed. In particular, a focus on language in its manifestations of remembering, narrative, and theorizing revealed a dynamic, constructive aspect that fit the pragmatists' and interactionists' views that behavior itself was transformative and not merely an applicative result (an output) from the "real cognitive" workings of information input, matching, retrieval, deduction, and action-plan configuration. Instead, we have the notions of dynamic memory, reconstructive memory, representing as an observable behavior (e.g., speaking as representing), and thinking as including non-verbal conceptualizing (vs. purely linguistic deduction).

The language-related foundations of situated cognition were well-established before AI research on comprehension and discourse by the pragmatists (see especially Dewey's [1939, p. 534] response to Russell), Wittgenstein's (1953) break with positivism in his analysis of the "language game," Ryle's (1949) distinction between knowing how and knowing that, Langer's (1942) distinction between discursive and presentational representation, Austin's (1962) view of language as speech acts, and the *general semantics* of Korzybski (1934).

Remembering: A situated theory of human memory is like an arch keystone that relates neural, symbolic information processing, and social views of cognition. Bartlett's (1932) notion of schemas was of course influential in qualitative modeling applications ranging from visual processing (e.g., Minsky's [1985] frames), to expert (knowledge-based) problem solving, and case-based reasoning (see Shapiro, 1992, pp. 1427-1443). Ironically, Bartlett's theory of memory is not based on storage of schemas, but rather active processes that are always adaptively constructed within action, biased through previous ways of working together, and when engaged "actively doing something all the time" (Bartlett, 1932, p. 201). Thus, he argued for a process memory, not a descriptive memory of processes or a pre-configured memory of stored procedures (see Clancey, 1997, Chapter 3).

Bartlett developed his theory by analyzing story recollection, showing how details, fragmentary ideas, and narrative were remembered and reconstructed. Loftus (1979) applied these ideas to reveal the improvisational aspects of memory in legal testimony. Bransford et al. (1977) and Jenkins (1974) demonstrated in experimental settings how linguistic-narrative memory blended phrases, roles, and themes in ways people did not realize. All of this suggested that remembering was not merely retrieving, but actively reconstructing and reactivating ways of thinking—and seeing, hearing, doing.

Schank's (1982) *Dynamic Memory* highlighted how past experience, such as previous encounters in a restaurant, shapes how we interpret and act in situations we conceive to be similar. He suggested that failure of expectation was particularly important in constructing new concepts. Although formalized by Schank's research group in a network of stored descriptions, this work emphasized the historical nature of knowledge. Learning and behaving are inseparable, with learning occurring *in behavior* itself, in contrast with the view that learning only occurs in reflective reconstruction after a problem solving episode is complete. Furthermore, normative (social) behavior can be described by scripts (Schank and Abelson, 1977), which are learned patterns of behavior based on the sequence of experience, not compiled from theoretical models about restaurants, etc. (See Clancey [2002] for further relation of scripts to situated cognition.)

Conceptual Structure: Focusing on aspects of story telling, metaphor, and comprehension, researchers explored how concepts are related in human understanding, how these relations develop, and how they are manifest in linguistic behavior. This work tended to underscore that knowledge is more than conceptual networks with nodes and links representing words and their attributes. Instead, conceptual understanding is not separate from sensory and gestural ("embodied") experience (Lakoff, 1987); relations can be mutually defining (e.g., Wilden's exposition of dialectics, 1987); and a linguist's reduction of speaking to grammatical form and definitions "alienates language from the self" (Tyler, 1978). Similarly, Bruner (1990) highlighted the role of narrative in the construction of the self. Narrative is a representational form that transcends individual concepts through "tropes" of Agents, Scenes, Goals, etc. that have interpretive value, but not logical "truth conditions" (pp. 59-60). Thus understanding the genre, development, and function of narrative requires systems thinking.

These theoretical perspectives each sought in their own way to avoid the pitfalls of a narrow *structuralism*, which tended to localize behavior, knowledge, or meaning in one box of a mental process (e.g., conceptual memory, grammar), while ignoring the dynamic relations between systems (e.g., perception–conception–action and experience–self–participation).

Structuralism, attributed to Titchener (Plucker 2003), sought to explain behavior through the interaction of component mental structures, in the manner of a chemist explaining reactions in terms of atomic and molecular interactions. In his "core-context theory of meaning," Tichener suggested a complex system, by which "a new mental process (the core) acquired its meaning from the context of other mental processes within which it occurs" (ibid.). However, in most models of language until the mid-1980s (predating neural network models), these relationships were viewed as enumerable, definable, and in some respects admitting to further decomposition. Such descriptions ignore the dynamic relations across perception and motor systems, the conceptual organization of physical skills (especially in the dynamics of and between gesture, sound, and vision), as well as how social norms (e.g., conceptualization of activity) develop through interactions. In particular, cues and timing (as in a dance or complex group conversation) cannot be easily predescribed or linearly sequenced as "frames" or "schemas" in an knowledge base. Rather, the mental constructs are behavior patterns that are activated and adaptively improvised through ongoing tacit reflection (e.g., Schön's [1987] "knowing-in-action"). This is not to say that the grammatical descriptions of observable patterns are not accurate or useful theoretical tools, but to question whether such models can be identified with the neural structures that participate in the described behavior (see Clancey, 1997, Chapter 1).

Learning by Doing and Inquiry: As previously noted, the philosophical, psychological, and social development of the systemic view of cognition was often based on or directly influenced educational theory and designs. This is most obvious in the work of Dewey (who started his own school), Piaget, Bruner, and Papert, and then manifest in the analyses by Bamberger and Schön (1983) of learning in the arts such as music (Bamberger, 1991) and architectural design (Schön, 1987). Each explored an aspect of *constructionism* (Paper and Harel, 1991), which claimed that making and experimenting with physical objects (including drawings and notations) facilitates learning abstract concepts, as well as generating new insights that promoted abstract thinking. The theoretical claims were based on constructivism, but can be read as responding to AI's models of "knowledge acquisition": 1) learning is an active, willful process, not a passive comprehension and storage of facts and procedures to be later applied, 2) understanding requires experience, whether physical or in the imagination, such that multiple modalities of thought are coordinated, and 3) conceptual understanding relies upon perceptual-motor experience and simpler ideas, such that learning can be viewed and usefully guided in stages, which themselves require time and exploration to develop. Most importantly, this dynamic systems perspective does not deny the central role of formal representations (such as musical notation), but rather seeks to explain how representations are created and acquire meaning in practice.

Schön (1979, 1987) combined these ideas quite practically in his reinterpretation of Dewey's (1938) theory of inquiry (Clancey, 1997, pp. 207 ff). For example, his analysis of architectural design revealed how conceiving, articulating, drawing, and perceiving, and interpreting/reflecting were dynamically influencing each other in nested and parallel processes. Within the AI community, these ideas were first developed most visibly in the idea of *cognitive apprenticeship* (Collins, Brown, Duguid, 1989; Collins, Brown, and Newman, 1989), which produced a lively debate (Bredo, 1994; Greeno, 1997; Clancey [1992] response to Sandberg and Wielinga, 1991).

In related naturalistic studies, Gardner (1985) examined the varieties of intelligence, emphasizing skills in different modalities that people exhibited or combined in different ways. This work had the dual effect of highlighting what schoolwork and tests ignored and how the verbal emphasis of problem solving research over the previous two decades ignored physical, visual, and even interpersonal forms of knowledge.

Animal Cognition, Evolution, and Ecology Feedback: Biology + Cognition

In many respects, the application of systems thinking that was so confusing and indeed threatening to psychologists and AI researchers in the 1970s and 80s, was already well-established in biology, as scientists came to realize that neither the cell nor the organism could be isolated for understanding the sustenance, development, or evolution of life. Systems thinking, involving notions of dynamic and emergent interactions, was necessary to relate the interactions of inherited phenotype, environmental factors, and the effect of learning. Indeed, in reviewing the literature, one is struck at how ethologists (studying natural behavior of animals), neurologists (focusing on neural and cell assemblies), and cyberneticists (forming cross-disciplinary theories of systems and information) were meeting and writing about similar aspects of life and cognition. Yet, with a more narrow focus on intelligence, and then "expertise," the relevance of these broad theories to AI and cognitive science was not recognized for several decades. So ironically, even though one can easily see cybernetics as a kin to situated cognition, cybernetics was not presented in AI textbooks as a necessary background for studying the nature of intelligence.

Cybernetics: The intersection of neurology, electronic network theory, and logic modeling around WWII was popularized by Norbert Wiener (1948), who defined cybernetics as the study of teleological mechanisms, exemplified by the feedback mechanisms in biological and social systems. As we have seen throughout, the notions of memory and localization were central. von Foerster wrote: "The response of a nerve cell does *not* encode the physical nature of the agents that caused its response. Encoded is only 'how much' at this point on my body, but not 'what'" (von Foerster 1973, pp. 214–

215). That is, the observer's described world of objects, properties, and events is not represented at this level in the nervous system; rather what is registered or "encoded" is a difference or change as the body interacts with its environment.

Similarly, Maturana and Varela's notion of "organizational closure" views *information* ("in-formation") as a dynamic relation and not something that flows into the organism as instructions or objectively meaningful packets. Maturana (1975, 1978, 1980, 1983) and Varela's (1987) theoretical framework of "the biology of cognition" also formalizes the complex systems concepts of *structural coupling* (mutual causal relations between organism and environment) and *autopoesis* (self-creating) (see Capra, 1996; Clancey, 1997, pp. 85 ff). Glasersfeld (1974) called this "radical constructivism" (see also Riegler, 2001).

Bateson (1972, 1988, 1991) was a central figure in the inquiry relating cybernetics, biology, and cognition. His reach was especially broad, including cultural anthropology, ethology, and family therapy. For example, his theory of the "double bind" in schizophrenia claimed that contradictory messages (e.g., a verbal command and incommensurate gesture) could disrupt conceptual coordination. Thus, in understanding schizophrenia as not only an internal mental-biological dysfunction but as a confused interpersonal dynamic—a disorganized relation between person and environment—Bateson brought a dialectic, ecological notion of information and communication to understanding development in biology and social science.

Ecological Psychology: Gibson (1979), a psychologist, developed a systems theory of cognition that explained behavior as a relation that develops in located action. For example, rather than saying a person can jump over a stream, one might say that a given stream affords jumping when a person is running as he approaches (Turvey and Shaw, 1995). Such an *affordance* is a dynamic relation between a moving person and the environment, not located in the person or in the stream. Turvey and Shaw further developed this theory relating perception and motion, characterizing the organism-in-its-environment as a reciprocal relation, seeking a biologically relevant information theory (see Clancey, 1997, Chapter 11). They explicitly argued against the "cognitivist" perspective; see especially Shaw and Todd (1980), elucidated by Clancey (1997, pp. 280ff). Within psychology this alternative view was also called *contextualism* (Hoffman and Nead, 1983).

Ethology: From a historical perspective, perhaps the oddest disconnection in the science of cognition is the study of intelligence by early AI and cognitive scientists research without reference to animal research. In part, this could reflect perhaps a resistance to attribute cognition per se to animals, as "animal cognition" only flourished on the scientific scene in the 1980s (e.g., Roitblat, Bever and Terrace, 1984; Gould, 1986; Griffin, 1992). And certainly the Skinnerian behaviorist psychology of the 1950s and 1960s appeared to be more about rote animal training than problem solving. Nevertheless, the work of Konrad Lorenz, Karl von Frisch, and Nikolaas Tinbergen, winners of the Nobel prize in 1973, was well known through the 1950s. In the autobiography accompanying his Nobel lecture, Lorenz (1973) says he early on believed that his responsibility ("chief life task") was to develop an evolutionary theory of animal psychology, based on the comparative study of behavior. He was influenced by Karl Bühler and Egon Brunswick to consider a psychology of perception tied to epistemology;

similarly, he found in Erich von Holst, "a biologically oriented psychologist who was, at the same time, interested in theory of knowledge."

Frisch's seminal work, *The Bee's Language* (also "dance", published in German in 1923), is an exemplary study of situated (over time and location) animal behavior in groups (compare with feeding pellets to pigeons in a cage apparatus). Tinbergen's (1953) *The Herring Gull's World* teased apart the stimuli organizing social behavior patterns.

The study of animal navigation and social behavior is especially profound for AI and cognitive science because it reveals what simpler mechanisms—fixed programs with perhaps limited learning during maturation—can accomplish. Studying animals forces the scientist to acknowledge that an observer's descriptive world maps and principled rule descriptions of behavior (as might be found in an expert system), although useful to model animal behavior, could not be the generative mechanism in creatures lacking a language for modeling the world and behavior. This realization, pioneered by Brooks (1991), produced in the late 1980s a wide variety of animal-inspired mechanisms in a field called "situated robotics" (Clancey, 1997, Part II). The formulation of a theory of dynamical (complex) systems (termed "chaos systems") by Prigogine (1984) helped explain, for example, ant organization around a food source. In particular, the complex systems concept of *dissipative structures* (in which decreased energy becomes a source of increased order) inspired Steels' (1990) designs of self-organizing *robotic systems*.

Related work in "artificial life" (Resnick, 1997) in the 1980s sought to explain the development of systemic organization and emergent properties through the same cellular automata mechanisms that inspired Minsky in 1950. Kaufmann (1993) moved this investigation to molecular biology, interestingly combining the "strings of symbols" idea from information processing with the notion of self-organizing, feedback systems. He suggested the applicability of this approach to understanding economics, conceptual systems, and cultural organization—hence "the new kind of science" (Wolfram, 2002).

Neurology and Neuropsychology: Neurology + Cognition

Neuroscience, inspired by mechanisms of computational connectionism and grounded in magnetic resonance imaging (MRI) and related methods for inspecting brain processes, raced ahead in the 1990s with new models of categorization learning, visual processing, sensory memory, and theories relating emotion to cognition (Damasio, 1994).

As previously related, connectionism derived from the work of Lashley, Head (1920), Ashby, Hebb, and many others, and predated computational modeling of problem solving. Rosenfield (1988, 2000), Edelman (1987), and Freeman (1991) directly addressed and often critiqued cognitive theories, showing that they were incoherent from the perspective of complex systems theory and were biologically implausible.

Similarly, Sacks (1987), a neurologist, used case studies of how patients survive and adapt to reveal how neural processes, the environment, and issues such as selfhood interact to inhibit or enable mental experience. Sacks was especially adept at showing how conventional neurology's tests and dysfunctional categories veritably "decomposed" the patient by an inventory of deficits, while instead the patient's experience developed as a compensatory reorganizing process of preserving and re-establishing identity (persona). Notice how the idea of a person—involving personal projects (Sacks, 1995), temperament, friendships, cherished experiences, etc.—is very different from the typical antiseptic reference to "humans" as a subjects of study, in which it becomes all too easy to then ignore issues of identity and consciousness.

Contemporary theories of knowledge and learning: Anthropology + Cognition

At this point in the story, the history of science by the late 1980s becomes the contemporary development of "situated cognition" in AI and cognitive science (Clancey, 1997). Some social scientists were shifting form third-world sites to business and school settings in the USA, Europe, and South America, focusing especially on learning (e.g., Lave and Wenger, 1991). These researchers were especially influenced by Dewey, Vygotsky, Piaget (e.g., Cole and Wertsch, 1996), Bateson, Gibson, Hall, and Mead (e.g., Suchman, 1987). Often anthropology provided an organizing theoretical and methodological perspective (Greenbaum and Kyng, 1991). Studies of learning and instructional design were transformed to relate information and participatory processes in activity systems (Greeno, 2006).

Drawn in perhaps by the formation of Cognitive Science Society in 1980, some social scientists and the psychologists reacted especially to the theory that all problem-solving behavior was generated from a pre-formulated plan derived from verbally defined goals and deductive inference about problem-solving methods (Schön, 1987; Agre, 1997). For example, Lave (1988) questioned whether human expertise could be inventoried and indeed stored in a "knowledge base." *Situated action* and *situated learning* sought to expose how people actually behaved, what they knew, how they learned during work. Some of the earliest proponents were Scribner and Cole (1973), Rogoff and Lave (1984), and Suchman (1987). The previously mentioned ideas of cognitive apprenticeship developed in this academic community of practice, which resided predominantly at UC Irvine and San Diego, Xerox-PARC, Pittsburgh's Learning

Research and Development Center (LRDC), MIT's Media Lab, and the Institute for Research on Learning.

Foreshadowed Dilemmas in Cognitive Psychology and AI

AI and cognitive scientists were aware of gaps and oddities in mainstream theories of intelligence through the 1960s and 70s. However, any science must exclude certain phenomena (one is tempted to say, "certain complexities"). Thus, it is no surprise that although engaging invited talks and textbook final chapters (e.g., Neisser, 1976) might mention autism, dreaming, and emotion, there was no coherent theory of consciousness. (Indeed, the new reputability of the topic "consciousness" in cognitive science during the 1990s was somewhat like the admission of "cognition" into talk about animals in the 1980s.) Psychiatric disorders for example were difficult to make sensible from the perspective of a single semantic network of concepts and relations—supposedly modified in long-term memory and processed by a central processing unit (CPU) that was by assumption identical in every human brain.

Nevertheless, some cognitive phenomena stood out as requiring consideration: commonsense knowledge (nobody needs physics calculations to know whether a spilled liquid is likely to reach the end of a table), the relation of imagery and discursive thought (Langer, 1942), the subjective nature of meaning versus the idea that knowledge consisted of stored proposition models of facts and rules (highlighted by the philosophical analysis of Winograd and Flores [1986]), language learning (how does a child learn so much grammar from so few examples?), ill-structured problems (Simon, 1973), musical creation and performance (e.g., Smoliar, 1973), how symbols in a cognitive system are "grounded" (Harnad, 1990), and so on.

Reflecting on the problems scientists had in bringing a complex systems perspective to AI and cognitive science, Clancey (1997, pp. 345 ff) formulated a set of heuristics for scientists: Beware an either-or mentality (e.g., knowledge is either objective or arbitrary); Try both narrow and broad interpretations of terms; Given a dichotomy, ask what both positions assume; Beware imposing spatial metaphors; Beware locating relations; Try viewing independent levels as co-determined; Don't equate a descriptive model with the causal process being described; Recognize that first approximations may be overstatements; Be aware that words sometimes mean their opposites; Enduring dilemmas are possibly important clues; Periodically revisit what you have chosen to ignore; Beware of building your theory into the data; Locate your work within historical debates and trends; "It's not new" does not refute a hypothesis; Beware errors of logical typing; Recognize conceptual barriers to change; To understand an incomprehensible position, start with what the person is against; Recognize that the "born again mentality" conceives sharp contrasts; Recognize how other disciplines study and use as tools different aspects of intelligence; Recognize the different mental styles of your colleagues.

Can we summarize the meaning of situated cognition itself, as seen through all the scientific disciplines over the past century? As stated, an all-encompassing generalization is the theory of complex systems. From an investigative standpoint, the one essential theoretical move is *contextualization* (perhaps stated as "anti-localization," in terms of what must be rooted out): We cannot locate meaning in the text, life in the cell, the person in the body, knowledge in the brain, a memory in a neuron. Rather, these are all active, dynamic processes, existing only in interactive behaviors of cultural, social, biological, and physical environment-systems. Meaning, life, people, knowledge, etc. are not arbitrary, wholly subjective, culturally relative, totally improvised, etc. Rather, behaviors, conceptions, emotional experiences, etc. are constrained by historically developed structural relations among parts and subprocesses in different kinds of memories—neural, artifactual, representational, and organizational—and dynamically constrained-in-action across system levels.

Many difficult problems remain in understanding learning, language, creativity, and consciousness. From a computer scientist's standpoint, looking out over the vast landscape of more than a century of exploration, the nature of memory and development still appears pivotal. Almost certainly, elucidating the emergent structures and regulatory processes of genetic biology (Carroll, 2005) will inspire more complex computational theories and machines with perhaps reconstructive procedures and hierarchies. The nature of conceptualization and hence consciousness will gradually be articulated, comprising a complex order of molecular, physiological, neural, coordination memory, and activity systems. The nature of the self—unfolding, self-organized, and willfully determined—will be revealed as the essential cognitive dialectic: Controlling yet biased by ideas, open to change yet inconsistent and inhibited, prone to ennui and powerless anxiety, yet in joy of nature and companionship, always situated.

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