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Education

In its broadest sense, education spans the ways in which cultures perpetuate and develop themselves, ranging from infant-parent communications to international bureaucracies and sweeping pedagogical or maturational movements (e.g., the constructivist movement attributed to PIAGET). As a discipline of cognitive science, education is a body of theoretical and applied research that draws on most of the other cognitive science disciplines, including psychology, philosophy, computer science, linguistics, neuroscience, and anthropology. Educational research overlaps with the central part of basic cognitive psychology that considers LEARNING. Such research may be idealized as primarily either descriptive or prescriptive in nature, although many research ventures have aspects of both.

Descriptively, educational research focuses on observing *human* learning. Specific areas of study include expert-novice approaches, CONCEPTUAL CHANGE and misconception research, skill learning, and METACOGNITION. Expert-novice research typically explicitly contrasts the extremes of a skill to infer an individual's changes in processes and representations. Misconception research in domain-based education, such as NAIVE PHYSICS, NAIVE MATHEMATICS, writing, and computer programming, implicitly contrasts expert knowledge with that of nonexperts; a person's current understanding may be thought of in terms of SCHEMATA, frames, scripts, MENTAL MODELS, or analogical or metaphorical representations. Child development research often involves studying misconceptions. These constructs are used for both explanatory and predictive purposes. Research in general skill learning includes psychometric analyses of high-level aptitudes (e.g., spatial cognition), and topics such as INDUCTION, DEDUCTIVE REASONING, abduction (hypothesis generation and evaluation), experimentation, critical or coherent reasoning, CAUSAL REASONING, comprehension, and PROBLEM SOLVING. Some of these skills are analyzed into more specific skills and malskills such as heuristics, organizing principles, bugs, and reasoning fallacies (cf. JUDGMENT HEURISTICS). Increasingly, metacognition research focuses on an individual's learning style, reflections, motivation, and belief systems. Research on learning can often be readily applied predictively (i.e., a priori). For example, Case (1985) predicted specific cognitive performance in balance-beam problem solving within defined stages of development.

Prescriptive elements of education are quite diverse. Some liken such elements to the engineering, as opposed to the science, of learning. Products of prescriptive education include modest reading modules, scientific microworlds, literacy standards, and assessment-driven curricular systems (e.g., Reif and Heller 1982; Resnick and Resnick 1992). The advent of design experiments (Brown 1992; Collins 1992) represents a kind of uneasy compromise between the rigorous control of laboratory research and the potential of greater relevance from classroom interventions.

Educational proponents of situated cognition generally highlight the notion that individuals always learn and perform within rather narrow situations or contexts, but such proponents are often reticent to offer specific pedagogical recommendations. Situated cognition variably borrows pieces of activity theories, ECOLOGICAL VALIDITY, group interaction, hermeneutic philosophies, direct perception, BEHAVIORISM, distributed cognition, cognitive psychology, and social cognition. It generally focuses on naturalistic, apprentice-oriented, artifact-laden, work-based, and even culturally exotic settings. This focus is often represented as a criticism of traditional school-based learning—even though some situated studies are run in schools (which are arguably natural in our society). Situated cognition's critics see it as an unstructured, unfalsifiable melange with near-infinite degrees of explanatory freedom and generally vague prescriptions. Recent disputes between the situated and mainstream camps seem to center on the questions, "What is a symbol?", "How can we separate a learner from a social situation?", and "Is transfer of training common or rare?" (e.g., Vera and Simon 1993, and commentaries). The disputes mirror many core issues from other cognitive science disciplines, as well as questions about the goals of social science.

Several cognitive theories have descriptive, predictive, *and* prescriptive applications to education. For instance, the ACT-based computational models of cognition (Anderson 1993) attempt to account for past data, predict learning outcomes, and serve as the basis for an extended family of intelligent tutoring systems (ITSs). These sorts of models might incorporate proposition-based semantic networks, "adaptive" or "learning" production systems, economic or rational analyses, and representations of individual students' strengths and weaknesses. The contrasts among various computer-based categories of learning-enhancement systems have not been sharp (Wenger 1987). These categories include ITSs, computer-aided instruction, interactive learning environments, computer coaches, and guided discovery environments. Some distinctions among these categories include (a) whether a model of student knowledge or skill is employed, (b) whether a relatively generative knowledge base for a chosen domain is involved, (c) whether feedback comes via hand-coded (or compiled) buggy rules (and lookup tables) or via the interpreted semantics of a knowledge base, and (d) whether a novel, more effective representation is introduced for a traditional one. Superior ITSs demonstrate great effectiveness relative to many forms of standard instruction, but currently have limited interactional sophistication compared to human tutoring (Merrill et al. 1992). Specific ITSs often spawn the following question from both within and without cognitive science: "Where is the intelligence, or the semantics, in this system?"

Distributed cognition systems also face this question, although many proponents are unconcerned about philosophical semantics-from-syntax queries. Constraint-based and connectionist models are not yet commonly employed in educational ventures (cf. Ranney, Schank, and Diehl 1995), which seems surprising, given the efforts focused on learning in parallel distributed processing models of cognition, BAYESIAN NETWORKS, artificial neural or fuzzy networks, and the like.

As with some ITSs, cognitive science approaches to education, in general, often focus on improving students' knowledge representations or on providing more generative or transparent representations. Many such representational systems have evolved with computational technology, particularly as graphical user interfaces supplant text-based, command-line interactions. Clickable, object-oriented interfaces have become the norm, although the complexity of such features sometimes overwhelms and inhibits learners.

Most recently, the Internet and World Wide Web have spawned many research ventures, for instance, involving collaborative learning environments that include the integration of technology and curricula. However, an ongoing danger to education is the proliferation of well-funded research projects developing potentially promising technologies that, relative to the vast majority of classrooms, (a) require intolerable levels of equipment upgrades or technical and systemic support, (b) are unpalatable to classroom teachers, and (c) simply do not "scale up" to populations of nontrivial size (cf. Cuban 1989).

See also COGNITIVE ARTIFACTS; COGNITIVE DEVELOPMENT; HUMAN-COMPUTER INTERACTION

—Michael Ranney and Todd Shimoda

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Electric Fields

See ELECTROPHYSIOLOGY, ELECTRIC AND MAGNETIC EVOKED FIELDS

Electrophysiology, Electric and Magnetic Evoked Fields

Electric and magnetic evoked fields are generated in the brain as a consequence of the synchronized activation of neuronal networks by external stimuli. These evoked fields may be associated with sensory, motor, or cognitive events, and hence are more generally termed *event-related potentials* ERPs) and *event-related magnetic fields* (ERFs), respectively. Both ERPs and ERFs consist of precisely timed sequences of waves or components that may be recorded noninvasively from the surface of the head to provide information about spatio-temporal patterns of brain activity associated with a wide variety of cognitive processes (Heinze, Münte, and Mangun 1994; Rugg and Coles 1995).

Electric and magnetic field recordings provide complementary information about brain function with respect to other neuroimaging methods that register changes in regional brain metabolism or blood flow, such as POSITRON EMISSION TOMOGRAPHY (PET) and functional MAGNETIC RESONANCE IMAGING (fMRI). Although PET and fMRI provide a detailed anatomical mapping of active brain regions during cognitive performance, these methods cannot track the time course of neural events with the high precision of ERP and ERF recordings. Studies that combine ERP/ERF and PET/fMRI methodologies are needed to resolve both the spatial and temporal aspects of brain activity patterns that underlie cognition.

At the level of SINGLE-NEURON RECORDING, both ERPs and ERFs are generated primarily by the flow of ionic currents