Current Developments in Educational Technology Programs
Doctoral Training in the Learning Sciences at Northwestern University

Roy D. Pea*
Chair, Learning Sciences Ph.D. Program
Northwestern University

John Evans
Professor of Education and the Learning Sciences
Northwestern University

At a time when fresh approaches to the critical problems in education are desperately needed, future educators and researchers in the field of education must equip themselves to confront the challenges of educational reform creatively. Northwestern University is addressing these challenges through its new doctoral program in the Learning Sciences. Launched in 1991 and administered through Northwestern's School of Education and Social Policy, the interdisciplinary Learning Sciences program will prepare future leaders to advance innovative approaches to examining and addressing the practices of learning and teaching, broadly conceived. Problems of learning underlie issues of education, training, and lifelong contributions to society. The research-informed use of technology in education is critical as technology has come to play an ever more prevalent role in work, science, government, and human activities broadly considered. The integration of computing, telecommunications, and media-rich information technologies will come to play central roles in the processes of learning and teaching. These vital concerns demand attention from the most rigorous research and theory available, which will contribute the understanding necessary to advance both the practice and sciences of learning. The Learning Sciences program is devoted to this agenda.

The goal of the Learning Sciences Ph.D. program is to advance the research and development of innovative learning environments (including small-group learning and network-supported, remote collaboration), human cognition as it relates to the processes of learning and teaching, and multimedia computing and telecommunications technologies that may effectively support these processes. With advances in networking and models of collaborative learning, even learners from underserved populations and those in remote areas would have the opportunity to experience the most advanced approaches to teaching and learning and could gain access to information and resources that were previously unavailable to them. Research in the Learning Sciences is aimed at creating environments that offer all students a rich variety of opportunities for learning to think more effectively and more creatively.

Northwestern has assembled a distinguished initial faculty of 20 members from diverse departments, including computer science, education, psychology, and philosophy, with two new faculty members to be added during the 1993-94 academic year. Northwestern's Learning Sciences faculty have provided leadership in the cognitive sciences, artificial intelligence, and

research on learning and education, and contribute a diversity of theoretical and methodological perspectives to considerations of these problems, including but not limited to work in anthropology, artificial intelligence, cognitive and developmental psychology, computer science, educational research, linguistics, philosophy, and fields that develop strategies for promoting understanding and appropriate use of complex subject matter knowledge. The unique co-location of practitioners in these distinct disciplines brings a rich interdisciplinary perspective to the Learning Sciences Ph.D. program.

An active environment of research programs, supported by well-equipped facilities, promises rich opportunities for student participation in frontier investigations of learning in schools, workplaces, and other settings. Strategic alliances with corporate funders such as Andersen Consulting and Ameritech ensure attention to real problems of learning-at-work, while research activities with local schools and educational systems provide collaborations that may affect restructuring and offer models for constructive change. These resources are directed at understanding, effecting, and, importantly, replicating in educational activities the conditions that give rise to successful learning.

The design and use of technologies play a special role in Learning Sciences inquiries. Multimedia computing and telecommunications are increasingly prevalent in society, in the world of work, and in schools, as new tools for enhancing workplace activities and educational practices. Computer tools have also served as new instruments for investigative research on cognition, learning, and social interaction. Integrations of computing and video provide tools for deeper analyses of learning and teaching situations, and designs for novel architectures of learning, teaching, and assessment tools. Research and theory in the Learning Sciences Program pay both constructive and critical attention to these issues, by integrating three areas of specialization in its core coursework and methodological foundations:

Environments—Deepening understanding of the social, contextual, and cultural dynamics of learning in situations ranging from classrooms to out-of-school settings.

Cognition—Articulating scientific models of the structures and processes of learning and teaching of organized knowledge, skills, and understanding.

Architectures—Theory-guided design, construction, and use of multimedia computing and telecommunications technologies for supporting learning and teaching processes.

CURRENT STUDENTS

In 1992-93, there were 11 Learning Sciences Ph.D. students, with an expected enrollment of 20 in 1993-94 and 30 in 1994-95. Students, who have come from as far away as Canada, England, Israel, Korea, Singapore, and Yugoslavia to take part in the Learning Sciences program, have diverse backgrounds in such disciplines as comparative literature and music, as well as computer science, electrical engineering, psychology, and education. Graduate students in the Learning Sciences program range in age from 25 to 35 and approximately half of them have already acquired a master's degree before entering the program. An affiliated Ph.D. program in Computer Science through Northwestern's School of Engineering enrolled 43 students in 1992-93, and many of these students participate in the Learning Sciences course offerings and in the training activities of the affiliated Institute for the Learning Sciences (described later).

BACKGROUND

Research during the last two decades has led to a foundational shift in the disciplines and quality of research and theory contributing to the sciences of learning and teaching processes.

Influential interdisciplinary work in the cognitive sciences has taken problems of learning as its core topic. Research in the Learning Sciences is aimed at understanding and creating environments and educational strategies that offer learners from *all* cultural backgrounds a variety of opportunities for learning to think and act effectively, both within and outside of formal learning settings, and throughout the life span. Fundamental advances have occurred for such topics as the scientific understanding of the nature of expertise, culture-cognition relationships, constraints on learning, the social construction of knowledge, conceptual development, text comprehension, community and family influences on learning, relations between in-school and out-of-school learning, and the interactive and processing characteristics of successful learning conditions. National centers for research on aspects of these problems have been formed, programs and priorities of research funding in government agencies and private foundations have come to represent these concerns, and new scientific journals and societies have been established. National organizations of educational practitioners for diverse fields of study, such as science, mathematics, and reading, now routinely call for the practice of instruction, materials development, and teacher education to be more deeply informed by these new scientific understandings.

There has been a slow emergence of graduate training programs and departments that systematically reflect these developments. Although a significant number of cognitive science programs have appeared, few institutions have defined initiatives that systematically build on these scientific achievements to improve learning and education. Northwestern has created the Learning Sciences Ph.D. Program to contribute specifically to research and the training of professionals qualified to advance the scientific and humanistic understanding and practice of learning and teaching, broadly conceived. The training experience must contribute to the development of professionals ready to creatively define and respond to new issues that emerge in the changing conditions of learning in an increasingly global economy, in a multicultural society, and amidst a world of rapidly evolving patterns of work and life. Program graduates would be sought out for their capabilities to formulate and empirically address seminal questions; to engage in critical thinking, research, and development; and to provide leadership both within and at the crossroads of the cognate fields of the Learning Sciences.

FACULTY RESOURCES AND AFFILIATIONS

Reflecting the interdisciplinary nature of the sciences of learning, program faculty are drawn from several departments and schools of Northwestern, including the School of Education and Social Policy, the Department of Electrical Engineering and Computer Science, and the Department of Psychology. Two new faculty appointments in 1993-94 will further enhance the contributions of these departments and schools in the "Environments" specialization described later.

The Learning Sciences Program is affiliated with The Institute for the Learning Sciences, an interdisciplinary center devoted to basic and applied research in artificial intelligence, cognitive science, education, and educational software and related activities. The Institute was formed in September 1989, with founding support from Andersen Consulting, and is directed by Professor Roger C. Schank. It is a lively intellectual community of more than 180 scholars and scientists, corporate representatives, and professional programmers who collaborate to advance the research and development of the past 20 years of research in artificial intelligence through its refocusing on the educational needs of schools and corporations. Key research

areas include scientific problems of language, thought, and memory; the construction of computer programs that reason, learn, conduct conversations, display characteristics of human memory, plan, and contain realistic models of the world; the understanding of how children learn language, learn to think, plan, and reason; education, especially the development of effective teaching-learning methods from a plurality of cultural and social contexts; subject matter learning, especially in situations presenting intellectual difficulties, such as reading comprehension, and reasoning in mathematics, science, and with technology; augmentation of intelligent activity with cognitive technologies; computer vision; models of emotion, human problem solving and decision making; and qualitative reasoning about physical systems. Research activities are supported by a state-of-the-art, networked computing infrastructure and an unusual commitment to building technologies and supporting activities that function effectively in the complexities of human learning environments.

Learning Sciences faculty are actively involved in the publishing world as well, as founders and editors of journals such as *Cognition, Cognition and Emotion, Cognition and Instruction, Cognitive Science, Computational Intelligence, Discourse Processes, Interactive Learning Environments, Instructional Science, Journal of the Learning Sciences, Journal of Metaphor and Symbolic Activity,* and *Machine Learning;* as regular contributors to disciplinary journals in their respective fields; and as book authors and book series editors with distinguished international presses.

Following is a listing of Learning Sciences faculty and their areas of specialization:

Professors

- Allan Collins
  Ph.D. University of Michigan, 1970
  Professor of Education
  Theories of knowledge in teaching and learning; assessment; technologically based school reform.

- Karen C. Fuson
  Ph.D. University of Chicago, 1972
  Professor of Education
  Mathematics and learning; cognitive development.

- Dedre Gentner
  Ph.D. University of California at San Diego, 1974
  Professor of Psychology
  Learning, reasoning, and conceptual change in adults and children, especially processes of similarity, metaphor, and analogy; mental models; acquisition of meaning.

- Douglas L. Medin
  Ph.D. University of South Dakota, 1968
  Professor of Psychology
  Theories of learning, memory, and induction; concept and classification learning; medical problem solving; comparative psychology.

- Andrew Ortony
  Ph.D. University of London, 1972
  Professor of Education and Psychology
  Knowledge representation and language comprehension; models of cognition, motivation, and emotion.

- Roy D. Pea
  D.Phil. University of Oxford, 1978
  John Evans Professor of Education and the Learning Sciences
  (Learning Sciences Program Founder and Coordinator, 1991-1993)
  Learning-teaching processes and environments in science, mathematics, and technology; sociocultural foundations of complex learning; cognitive and conceptual development; multimedia learning and communication.

- Roger C. Schank
  Ph.D. University of Texas, 1969
  John Evans Professor of Electrical Engineering & Computer Science and Professor of Psychology and Education
  Theories of learning, understanding, teaching, and creativity; applications of artificial intelligence to education, memory processing, natural language understanding, and case-based reasoning.

Associate Professors

- Kenneth D. Forbus
  Ph.D. Massachusetts Institute of Technology, 1984
  Associate Professor of Computer Science
  Qualitative physics; cognitive simulation of analogy; inference systems.

- Brian J. Reiser
  Ph.D. Yale University, 1983
  Associate Professor of Education
  (Learning Sciences Program Coordinator, starting in 1993)
  Cognitive science; problem solving; intelligent tutoring systems.

- Christopher K. Riesbeck
  Ph.D. Stanford University, 1974
  Associate Professor of Computer Science
  Natural language analyzers; case-based reasoners; intelligent interfaces for training and tutoring.

- Sandra Waxman
  Ph.D. University of Pennsylvania, 1985
  Associate Professor of Psychology
  Issues of language and conceptual development from infancy through early childhood.

Assistant Professors

- Ray Bareiss
  Ph.D. University of Texas, 1988
  Assistant Professor (Research) of the Institute for the Learning Sciences
  Case-based reasoning; intelligent tutoring systems; multimedia computing; automated knowledge acquisition.

- Richard Beckwith
  Ph.D. Columbia University, 1988
  Assistant Professor (Research) of the Institute for the Learning Sciences
  Developmental and educational psychology.

- Lawrence Birnbaum
  Ph.D. Yale University, 1986
  Assistant Professor of Computer Science
  Natural language understanding; opportunistic planning; machine learning.

- Gregg Collins
  Ph.D. Yale University, 1987
  Assistant Professor of Computer Science
  Machine learning, especially planning and problem solving.

- Jeremiah M. Faries
  Ph.D. Princeton University, 1991
  Assistant Professor of Psychology and Education
  Memory organization and retrieval; analogy; problem solving; mental imagery; language comprehension; metaphor.

- Richard G. Feifer
  Ph.D. University of California at Los Angeles, 1989
  Assistant Professor (Research) of the Institute for the Learning Sciences
  Human and computer-based learning environments.

- Alex Kass
  Ph.D. Yale University, 1990
  Assistant Professor (Research) of the Institute for the Learning Sciences
  Case-based reasoning; story understanding; machine learning; models of creativity; computer-based education.

- Edward Wisniewski
  Ph.D. Brown University, 1989
  Assistant Professor of Psychology
  Cognitive science, conceptual combinations, and category learning.

Faculty Affiliates

- Michael Garet
  Ph.D. Massachusetts Institute of Technology, 1979
  Associate Professor of Education.

- Carol D. Lee
  Ph.D. University of Chicago, 1991
  Assistant Professor of Education.

- Stephen E. Toulmin
  Ph.D. University of Cambridge, 1948
  Avalon Foundation Professor of the Humanities and Professor of Philosophy.

- David E. Wiley
  Ph.D. University of Wisconsin, 1964
  Professor of Education.

CAREERS IN THE LEARNING SCIENCES

Graduates will be prepared to assume significant roles in advancing the understanding and practice of learning and teaching. Their work settings would include university research and teaching (such as in social science, computer science, or education departments); business, industry, or school system-based careers studying, designing, and/or implementing learning environments, broadly conceived to include learning materials, technologies (such as industrial training and educational software systems), and activities in their organizational contexts. Students of Learning Sciences faculty have often gone on to leadership positions in university faculties and industry.

THE Ph.D. PROGRAM IN THE LEARNING SCIENCES

The course of studies for the Learning Sciences Ph.D. reflects the philosophy that learning is both an *active* and a *reflective* process, requiring a breadth of experience in diverse research settings. Students' work in developing facility with theory and methods in the Learning Sciences is firmly rooted in laboratory work, as well as field experiences and studies of learning and education in nonlaboratory settings. Foundational coursework and seminars are integrated with local and Chicago-area apprenticeships in research projects, and increasingly, independent research guided by faculty mentors. The fact that the program's faculty is diverse, both in its disciplinary background and its ideology, strengthens its purpose as a premier intellectual forum. Lively debates in regular colloquia contribute to this environment.

SPECIALIZATIONS OF THE LEARNING SCIENCES PROGRAM

Learning Sciences graduate students follow a core curriculum for approximately the first two years, as described later. Additional courses taken are based on consultation between the advisor and student. The remainder of the graduate training is dedicated to research under the direction of the Learning Sciences program faculty.

Corresponding to the breadth of faculty interests, three flexible tracks of specialization beyond the core are available for doctoral students. They focus on different levels of analysis: *Environments, Cognition,* and *Architectures.* The differences are primarily of relative emphasis— on either issues in teaching-learning environments (broadly construed to include sociocultural dynamics and cognitive aspects of learning), or computational and technological issues in building teaching-learning systems—and in the probable career paths of those pursuing these options. These specializations are also components of the core curriculum.

Those electing *Environments* will devote more of their training to rigorous study of theory, methods, and research for understanding cognitive, cultural, and social issues in the practices in which teaching-learning processes and technology use are embedded. Topics include small-group and network-supported collaborative learning, classroom discourse practices, cultural contexts of learning, social construction of subject matter understanding, and learning environments collaboratively designed with learners and teachers. Learning environments may but do not necessarily include the use of computational systems for learning and teaching. Methods include ethnographic study, discourse analysis, clinical interviews, protocol analysis, experimental design, and surveys. Such research often utilizes video recordings of learning-teaching interactions in settings such as schools and classrooms.

Those electing *Cognition* will devote more of their training to rigorous study of theory, methods, and research for understanding cognitive aspects of learning, especially for complex subject matter domains (e.g., mathematics, physics, technology). Topics include adaptive knowledge

structures and processes: experience-based mechanisms of learning and development; mental models: individual differences in aptitudes and learning strategies, including those affected by ethnicity, social class, and gender; novice-expert differences in categorization and problem-solving processes; skill acquisition; belief systems and conceptual change; explanation and under-standing: transfer of learning; and the related cultural and social factors embedded in these psychological processes. Methods include analysis of think-aloud protocols, building computer models of reasoning and learning, clinical interviews, and experimental psychological techniques.

Those electing *Architectures* will devote more of their training to rigorous study of basic and applied science issues concerning the design and development of effective computational and multimedia architectures for learning and teaching. Topics include architectures for guided discovery, incidental learning, collaborative learning, case-based tutors and coaches, intelli-gent tutoring systems, and designs for student-initiated, question-driven learning. Methods include artificial intelligence programming and theory, instructional design methods, and theory and research concerning learning-teaching processes from both cognitive and social science perspectives.

THE LEARNING SCIENCES CURRICULUM

An integrated body of coursework and apprenticing activities is designed for all students, regardless of specialization, so as to create a collegial learning culture in which faculty and students alike contribute to cultivating critical questions and shaping the programmatic directions of the interdisciplinary learning sciences. The training activities beyond seminars and lecture courses focus on learning-by-doing, in terms of apprenticeships in which students participate in ongoing research and development projects with program faculty. In this way, students come to understand, for future replication in their careers, the entire process of science and practice within the learning sciences, e.g., from planning and conducting research and analyzing results; to designing, building, and implementing new learning environments for real settings; to publication and dissemination efforts.

The core curriculum consists of seven quarter courses, three methods courses, three additional courses on Advanced Topics in the Learning Sciences selected in consultation with the student's advisor, and a number of additional lecture courses, seminars, research courses, and apprenticeship activities defined in consultation with the student's advisor from courses offered in the School of Education and Social Policy, the Department of Psychology, the Department of Electrical Engineering and Computer Science, and other units in the University. Students are normally expected to complete the first seven courses and the three methods courses in the first two years.

Core Courses in Learning Sciences

The seven quarter courses, to be taken by all Learning Sciences students, include:

- The first quarter *Learning Sciences Proseminar*, taught by Learning Sciences faculty. The aim here is to introduce the fundamental concepts, methods, and theories that constitute the learning sciences, as realized through the research of our faculty. Student teams analyze the work of a given faculty member each week and present synthetic discussions with that faculty member present for questions and discussion. The concepts, methods, and theories are likely to be drawn from the contributions of such fields as artificial intelligence, cognitive science, cognitive and developmental psychology, cognitive and cultural anthropology, education, epistemology, humanities, linguistics, organizational science, and subject matter disciplines.

- Two courses in *Learning Environments*: One course focuses on design of learning environments (including instructional materials and design of activities), effective learning conditions in nonschool settings, and the assessment of learning environments. One course critically examines the philosophical and historical foundations of educational technology. Together, these courses cover research on naturalistic and designed learning environments, different educational philosophies and examples of their embodiments in educational technology and learning environment design, and examples from different methodological perspectives of the systematic study of learning-teaching processes and outcomes resulting from learning environments.

- Two courses in *Cognition*: One is an introductory course on cognitive science models of learning and problem solving, providing interdisciplinary treatment of key research and theory. The second course may be selected from a list of courses on cognitive development and learning.

- Two courses in *Artificial Intelligence*: These courses examine theoretical issues relating to human and machine intelligence and the practical issues of implementing aspects of intelligence on machines. Some central issues include: methods of representing complex knowledge, the organization and access of large yet flexible memory systems, modifying knowledge based on experience (learning), planning and problem solving, inferential reasoning, and language processing.

Because students may have previously completed coursework meeting any of these requirements, a review determines whether students may, with faculty advisement, replace one of these courses with more advanced coursework.

Methods Courses

All students are also required to take three methods courses, with one or more additional methods courses recommended, depending on the student's area of specialization. One course is centered on artificial intelligence programming and system design. A second course provides rigorous experience and theory in observational methods and techniques for studying human activity, emphasizing observational fieldwork on learning environments, and including study of learning in situ. A third course is on statistics and experimental design.

Advanced Topics Courses

At least three additional courses on Advanced Topics in the Learning Sciences are to be drawn from other offerings arranged with faculty advisement.

Research Apprenticeships

All Learning Science students apprentice to a variety of research laboratories and activities during their training. Students typically spend a total of three quarters participating in several different faculty-directed research activities during their first four quarters of study, at least one of which is outside their area of specialization.

Subsequent research requirements differ for the three concentrations. *Environments* students pursue field-based observation, design, and implementation research on learning environments; *Cognition* students focus on empirical studies of learning; *Architectures* students devote their efforts to designing and building computational systems. Students are expected to examine a plurality of cultural and social contexts during their training.

After the first year, doctoral students participate in a research activity in which they are assigned to work with one or more faculty members on a research project. Specific activities are tailored to the student's interests in consultation with the faculty advisor.

Other Requirements for the Degree of Doctor of Philosophy

- Student progress is reviewed annually by program faculty. Progress reports based on this review determine a student's eligibility to form a preliminary advisory committee and to take the preliminary examination.

- A written preliminary comprehensive examination in the Learning Sciences is required. This exam is constructed and revised on a regular basis by a representative Learning Sciences faculty group. The comprehensive exam includes two parts: a common set of questions covering the core topics for all students, and a divergent set of questions depending on the subsequent area of student specialization beyond the core.

- All doctoral students are required to complete a major, publication-quality predissertation paper reporting research conducted under the supervision of a Learning Sciences faculty member. This paper is prerequisite to admission to candidacy and is viewed as an apprenticeship experience rather than as independent research.

- The student must also pass an oral qualifying examination, in which the proposed dissertation topic is presented, and its significance to the development of knowledge in the learning sciences is discussed, as well as proposed research methodology and preliminary results.

- Advancement to candidacy is expected by the end of the third year of graduate study.

- A dissertation demonstrating original and significant research is required of each candidate, which is defended in the final oral examination.

SUMMARY

The pursuit of a Ph.D. in the Learning Sciences will provide students with a deep and action-oriented understanding of the dynamics of learning environments; the nature of the cognitive processes involved in learning and teaching; and how to design, construct, and use technology to support the learning and teaching processes. The program offers coursework tailored to the individual's needs and interests. The seven required core courses that introduce the student to the fundamentals of the learning sciences draw upon relevant concepts, methods, and theories from an array of fields and subject matter, including education, psychology, and computer science. Subsequent to the foundational courses, the student will typically focus on one of the three areas of specialization that he or she has experienced through the core curriculum: Environments, Cognition, or Architectures. Included in the course of study are methods courses and apprenticeships that provide hands-on experience in both laboratory and Chicago-area classroom settings. Upon completion of the program, graduates are ready to advance the understanding and practice of learning and teaching by assuming leadership roles in universities, school systems, industry, and in the broader society.

APPLICATION AND ADMISSIONS

For financial aid considerations, we hope to have all applications in hand by January 15 of each year, although applications received later than February 1 may be considered. Admission to the Learning Sciences program is highly selective. Learning Sciences students are eligible for multiyear funding, including summer support, which is competitively awarded.

For further information on the Learning Sciences Ph.D. Program, or to request a listing of technical reports published by The Institute for the Learning Sciences, please contact: Ms. Tina Turnbull, Graduate Program Coordinator, The Institute for the Learning Sciences, 1890 Maple Avenue, Evanston, Illinois 60201, U.S.A. 708-467-1332; electronic mail: tina@ils.nwu.edu; fax: 708-491-5258.