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An Assessment of Theoretical Frameworks for Learning Systems Research

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Introduction

The foundational research in learning from data has been conducted primarily in the fields of computer science, cognitive science, and statistics. The focus of the research has been the development and evaluation of learning algorithms. The technologies include symbolic and connectionist artificial intelligence techniques, the recently emerging techniques for knowledge discovery in databases, and statistical techniques. The field of information systems has unique opportunities to make research contributions toward the effective utilization of these learning technologies, due to its focus on the interactions between technologies, individuals, and organizations. The paper proposes a set of conceptual models and theories which are particularly suited to supporting various aspects of information systems research in learning systems. Each model or theory is placed within the context of the broadly-state research agenda -- which is to discover effective methods for designing technology-based organizational learning systems. Particular strengths and weaknesses of the models and theories are proposed relative to this agenda. The paper is intended to contribute to a dialog regarding appropriate and useful theoretical contexts for information systems research in data-oriented learning systems.

Classes of Conceptual Models

There are several classes of conceptual models and theories that are useful to support various facets of learning systems research. The paper presents an abstracted discussion of three such classes:

1. Conceptual models of learning systems design
2. Epistemological foundations: reasoning, inference, and knowledge
3. Models of organizational learning and knowledge creation

The abstract is organized in the following manner. Each of the three classes is summarized in table format, describing the names of the primary research contributors, their research areas, and the nature of their research contribution. Following each table are explanatory notes and arguments on the strengths and weaknesses of the contributions in the context of information systems research.

Models for Learning Systems Design

Conceptual models of learning systems design		
Contributor	**Research Area**	**Nature of the Contributions**
Pat Langley	machine learning	• high-level model of learning, including definitions of the major constructs involved and their interactions
Ashwin Ram	computer science, cognitive science	• foundational research on goal-directed learning, and on the use of questions as learning goals
Herbert A. Simon	artificial intelligence, management science	• the science of design • science of the artificial vs. the natural world

Langley: Langley (1996) has proposed a model and definition of learning portraying the interactions between four primary constructs: knowledge, environment, learning, and performance. The constructs are intentionally broad to allow use of the model in a variety of contexts -- not just in support of machine learning research. When compared to similar models and definitions from related subfields -- e.g. the definition of knowledge in knowledge discovery systems -- Langley's approach is less restrictive. It is thus valuable as a general communication framework for locating particular learning systems research questions, the "subconstructs" involved in the questions, and the specific interactions between these more detailed constructs.

Ram: Much of Ram's work (e.g., Ram & Leake, 1995) examines the use of goals in the learning process. In earlier work Ram has proposed a "theory of questions and question-answering." He makes the conceptual connection between "goals" and "questions" -- i.e. questions serve as goals, focusing attention and providing the learning intent. In early information systems research, Rockart established the importance of "chief executives defining their own ***data*** needs." With current learning technologies, this concept needs to be extended to include "***knowledge*** needs" -- i.e. to incorporate user questions which involve inferencing vs. direct data retrieval. Ram's work can provide useful conceptual foundations for such extensions. Questions have the potential to be a central construct in applied learning systems research, linking learning goals to the technologies capable of answering them.

Simon: Simon's arguments for "a science of design" (Simon, 1981) offer an ontological orientation for the overall problem of "learning systems design." Simon argues that the mission of applied fields (including information systems) is to match technologies to environments in optimal ways, which is a design task. The criteria for optimality is subjective and human-defined. Therefore the design challenge is better informed by "artificial science" as opposed to natural science. He proposes that design problems be conceptualized as *means-ends* analyses. For example, in the context of learning systems designs, *ends* can relate to goals or questions, and *means* relate to technology features. If organizations can associate a potential value or utility with specific learning goals, Simon's scheme provides a framework for calculating subjective "goodness" of various learning systems design proposals. Recognizing that learning systems design is a design problem is also useful in detailing the research questions within the problem space. Design and configuration problems are by nature "combining" problems, with a vast number of potential solutions. Thus research which produces useful information to inform the design task is that which constrains or informs the combinations -- e.g. by deriving normative information on the "optimal" interactions between constructs involved. For example, a useful research goal is to identify the optimal match between attributes of an organization's learning environment, and features of learning technologies.

Models of Reasoning, Inference, and Knowledge

Epistemological foundations: Reasoning, inference, and knowledge		
Contributor	**Research Area**	**Nature of the Contributions**
Charles S. Peirce	philosophy and logic	• understanding of abductive and inductive logic
Ryszard Michalski	machine learning	• inferential theory of learning, including taxonomy of "knowledge transmutations"
Guus Schreiber Bob Wielinga Joost Breuker	knowledge-based systems	• foundational research on KADS, a structured approach to knowledge-based systems based on reuse of generic task models and inference types

Peirce: Charles S. Peirce is a philosopher and logician who was interested in understanding the "logic of science" -- i.e. particularly inductive and abductive logic -- in addition to deductive logic, which had been emphasized to a greater degree in the field of epistemology. His work is critical as a basis for learning systems because inductive and abductive logic create new (but uncertain) knowledge, whereas deductive

logic applies existing knowledge to derive certain conclusions. The frameworks by Michalski and others in knowledge-based systems are built upon the work of Peirce.

Michalski: The "inferential theory of learning" (ITL) is proposed by Michalski (1993) as a foundational framework for *multistrategy task-adaptive learning* (MTL*)*, which attempts to improve the overall quality of machine learning systems by offering an array of learning styles. The ultimate goal in MTL is to dynamically select learning strategies (as detailed in the ITL) on the basis of the task, the input information, the learner's background knowledge, and the learning goal. The ITL proposes a taxonomy of knowledge operations for various types of inferences ("knowledge generation transmutations") and retrievals ("knowledge manipulation derivations".) The ideas of MTL and ITL have potential for being applied in a larger context as a model for conceptualizing the mix of organizational learning questions, i.e. applying the ideas of multistrategy learning at the planning level vs. the execution level. ITL will require extensions to support this broader function, particularly to better represent the technological capabilities from areas other than machine learning -- e.g. to support the highly exploratory questions that are common in knowledge discovery applications, and to better support a mapping to a robust set of traditional descriptive and inferential statistics. The ITL has unifying potential as the basis for an information systems view of learning in that descriptive questions (e.g. those supported with SQL queries) can be mapped to the same framework as learning technologies which derive predictions and explanations. From the user's point of view, all of these are viewed simply as questions.

Schreiber, Wielinga, & Breuker: The KADS methodology (Schreiber, Wielinga, & Breuker, 1993), which has wide acceptance in Europe, provides a set of inference types that has many similarities to the set defined by Michalski in the ITL. KADS provides a somewhat different view of knowledge structures since it is not a product of machine learning, but rather grew out of attempts to provide generic task models to be used as templates and architectural guides to the construction of knowledge-based systems. It builds upon B. Chandrasekaran's work on the definition of generic task models, e.g. for diagnosis, configuration, and design tasks. A potential contribution of the KADS research is its association of inference types with task types -- i.e. specific types of inferences are specified as steps within generic task models. This provides a potential basis for research in learning systems at higher levels of granularity -- i.e. in terms of *sets* of inferences, or machine learning operations used in the course of a task execution. *Tasks* relate to higher forms of questions, which are necessarily decomposed into lower level knowledge operations for execution purposes. Tasks involve supporting *decisions*, which are in turn related to supporting questions. These higher levels of granularity -- the task and decision levels -- may be important in organizational planning stages of learning systems design. Certain types of learning goals may be more easily described in terms of tasks and decisions vs. specific lower-level learning operations.

Models of Organizational Learning

Models of Organizational Learning and Knowledge Creation

Contributor	Research Area	Nature of the Contributions
Daft, R.L. Weick, K.E.	Organizational Science, Information Systems	• model of organizational learning in which data interpretation plays a central role
Ikujiro Nonaka	Organizational Science	• theory of organizational knowledge creation

Daft & Weick: There are many models of organizational learning proposed in the literature, including, e.g., those of Huber, Argyris, Kim, and Garvin. The model proposed by Daft & Weick, however, is unique in its emphasis on data interpretation as a key element of organizational learning. The model includes three sequential phases: 1) environmental scanning, 2) data interpretation, and 3) action. Data interpretation plays the central role in the model by creating knowledge from environmental data, and by linking the knowledge to the support of organizational goals, decisions and actions.

Nonaka: Finally, Nonaka's theory of organizational knowledge creation (Nonaka, 1994) provides a broad context which can be used to contrast data-oriented learning systems, which employ explicit knowledge, with other forms of organizational knowledge creation. Nonaka draws on experiences in Japanese firms, which tend to respect tacit and intuitive forms of human knowledge. In addition to knowledge creation, the model explicitly addresses knowledge communication and distribution, and transfer of knowledge between individuals and groups.

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