

Knowledge Objects and Mental Models

M. David Merrill, Professor
Department of Instructional Technology, Utah State University
merrill@cc.usu.edu

Abstract

This paper describes knowledge components that are thought to be appropriate and sufficient to precisely describe certain types of cognitive subject matter content (knowledge). It also describes knowledge structures that show the relationships among these knowledge components and among other knowledge objects. It suggests that a knowledge structure is a form of schema such as those that learners use to represent knowledge in memory. A mental model is a schema plus cognitive processes for manipulating and modifying the knowledge stored in a schema. We suggested processes that enable learners to manipulate the knowledge components of conceptual network knowledge structures for purposes of classification, generalization, and concept elaboration. We further suggested processes that enable learners to manipulate the knowledge components of process knowledge structures (PEAnets) for purposes of explanation, prediction, and trouble shooting. The hypothesis of this paper is that knowledge components and knowledge structures, such as those described in this paper, could serve as meta mental models that would enable learners to more easily acquire conceptual and causal networks and their associated processes. The resulting specific mental models would facilitate their ability to solve problems of conceptualization and interpretation.

1. Introduction

Cognitive psychology suggests that a mental model consists of two major components: knowledge structures (schema) and processes for using this knowledge (mental operations). A major concern of instructional design is the representation and organization of subject matter content to facilitate learning. In this discussion we suggest that the careful analysis of subject matter content (knowledge) can facilitate both the external representation of knowledge for purposes of instruction (knowledge objects) and the internal representation and use of knowledge by learners (mental models). Instructional designers have long recognized the importance of analyzing subject matter for the purpose of facilitating learning via appropriate knowledge selection, organization, and sequence. While instructional designers tend to focus on delivery systems (especially technology) and to a lesser extent on instructional strategies and tactics it is our hypothesis that the greatest impact on learning results from the representation and organization of the knowledge to be learned.

2. Knowledge Objects

Merrill and his colleagues in the ID₂ Research Group proposed a knowledge representation scheme consisting of knowledge components arranged into knowledge objects [1-5]. They suggest that almost all cognitive subject matter content (knowledge) can be represented

as four types of knowledge objects. *Entities* are things (objects). *Actions* are procedures that can be performed by a learner on, to, or with entities or their parts. *Processes* are events that occur often as a result of some action. *Properties* are qualitative or quantitative descriptors for entities, actions, or processes. They define knowledge via the components of a knowledge object. A knowledge object and its components are a precise way to describe the content to be taught. The components of a knowledge object are a set of defined containers for information.

- The knowledge components of an entity name, describe, or illustrate the entity.
- The knowledge components of a part name, describe, or illustrate a part of an entity,
- The knowledge components of a property name, describe, identify a value, and identify a portrayal corresponding to this value for the property.
- The knowledge components of an action name and describe the action and identify the process(es) triggered by the action.
- The knowledge components of a process name and describe the process and identify the conditions (values of properties) and consequences (property values changed) by the execution of the process and any other process(es) triggered by the process.
- The knowledge components of a kind name, describe, and define via a list of property values a class of entities, activities, or processes.

3. Knowledge Structures

A knowledge structure indicates the relationships among the components of a knowledge object or among different knowledge objects. Different kinds of knowledge structures have been identified for solving different kinds of problems. We will describe two such structures: a concept knowledge structure and a process knowledge structure.

3.1. Concept Knowledge Structure

The knowledge components for a concept (kind) are name, description, and definition (list of property values). A knowledge structure for a concept (Table 2) identifies the relationships among these knowledge components.

Table 1 Concept Knowledge Structure

	Superordinate Class		
	Coordinate A	Coordinate B	Coordinate C
Property 1	Value 1	Value 2	Value 3
Property 2	Value 1	Value 2	Value 3

This concept knowledge structure attempts to show the following relationships. A concept (kind) is always some subclass of another class (the superordinate class). There must always be at least two kinds or coordinate classes. Each subordinate coordinate class shares a set of properties with the superordinate class. Properties that have different values for two or more of the subordinate (coordinate) classes are called discriminating properties. Not all properties are discriminating properties, only

those who have different values for different coordinate classes. Class membership in a given coordinate class is determined by the set of values that the discriminating properties assume for members of this class.

3.2. Processes Knowledge Structure

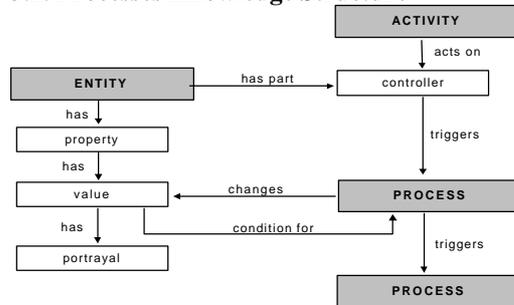


Figure 1 Process Knowledge Structure.

A process is knowledge about how something works. It answers the question, "What happens?" Processes are often taught at an *information-about* level. The process is sometimes demonstrated but the learner frequently has an incomplete or inaccurate mental model of the process. The components of a process include its name and description, a consequence that is defined as a change in a property value with the corresponding change in the portrayal of the entity (what happens?), and a set of conditions that is defined as values on properties (when?). A knowledge structure for a processes causal network is illustrated in Figure 1. This structure is called a PEAnet for Process, Entity, Activity Network. This structure is a very generic knowledge structure that can be used to represent almost any process. Processes are defined in terms of properties. A condition for a process is some value on a property. A consequence for a process is a change in the value of a property. When the value of a property of an entity changes the portrayal, either its appearance or its behavior, also changes in a corresponding way.

4. Mental Models

Cognitive psychologists have proposed a variety of theories of how knowledge is represented in memory (See Mayer, 1992). Schema theory postulates that learners represent knowledge in memory as some form of cognitive structure. A knowledge structure is a form of a schema. A knowledge structure represents the information that is required if a learner is to be able to solve problems. If the required information (knowledge components) and the relationships among these knowledge components is incomplete then the learner will not be able to efficiently and effectively solve problems requiring this knowledge. Mental models combine a schema or mental representation with a process for manipulating the information in the schema. Solving a problem requires the learner to not only have the

appropriate knowledge representation (schema or knowledge structure) but he or she must also have algorithms or heuristics for manipulating these knowledge components in order to solve problems.

5. Meta Mental Models

A meta model is a model about models. The knowledge structures described in this paper for concepts and processes and their associated cognitive processes for different types of problem solving using these knowledge structures provide a potentially useful meta mental model for a learner. If the learner knows the knowledge components and knowledge structure for a conceptual network, then he or she has a meta mental model for acquiring a conceptual network in a specific area. This meta mental model allows the learner to seek information for slots in the model. It provides a way for the learner to know if they have all the necessary knowledge components to instantiate their mental model. It enables the learner to extend their model of the concept under consideration by processing the concept schema for additional classes or by processing the schema to determine potential generalizations. If the learner knows the knowledge components and knowledge structure for a PEAnet then he or she has a meta mental model for acquiring a process mental model for some specific phenomena. The PEAnet structure enables the learner to determine if all the necessary knowledge components are present. By representing the phenomena in a PEAnet the learner can run mental experiments to see what consequences should occur under given sets of conditions. The learner can conduct mental "what if" experiments to predict what happens when the conditions change. The learner can represent very complex phenomena in a very systematic way providing a much better understanding of the phenomena under consideration. Furthermore the learner can describe devices or situations that don't work correctly using the PEAnet meta mental model. This allows the learner to help determine why a given process is not working by identifying the conditions that may be faulted.

6. References

- [1] Jones, M.K., Li, Z. & Merrill, M.D. (1990). Domain knowledge representation for instructional analysis. *Educational Technology*, 30(10), 7-32.
- [2] Merrill, M. D. & ID₂ Research Team (1993). Instructional Transaction Theory: knowledge relationships among processes, entities, and activities. *Educational Technology*, 33 (4), 5-16.
- [3] Merrill, M. D. & ID₂ Research Team (1996). Instructional Transaction Theory: Instructional Design based on Knowledge Objects. *Educational Technology*, 36 (3), 30-37.
- [4] Merrill, M. D. (1998). Knowledge Objects. *CBT Solutions*, March/April issue, pages 1, 6-11.
- [5] Merrill (In Press_a). Components of instruction: toward a theoretical tool for instructional design. *Instructional Science*.