The Guided Exploration Model of Problem Solving Discovery Learning

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This work is about problem-solving discovery learning in a general sense--how people approach and either succeed or fail in structured, rule-bound, problem-based learning activities. As Figure 1 illustrates, the “guided exploration” model of problem-solving discovery learning contains three principal activity domains. The inquiry and production domains (Anderson, 1983, 1990, 1993; Gagne, 1964, 1966, 1985) are "sub-systems" within the overall active learning system (Carroll, 1982; Carroll, et al., 1985; Carroll & Rosson, 1987; van der Meij & Carroll, 1998). The inquiry activity is where acquisition of critical declarative knowledge--facts, concepts, and rules--takes place. The production activity consists of the steps necessary to discover the procedural knowledge that enables successful enactment (Laurel, 1991) of a problem-solving goal. The production activity consists of hypothesis formation, acquisition of resources or tools needed for hypothesis testing, hypothesis testing, procedure discovery, and manifestation of results based on successful hypothesis formation. The learning that is required to accomplish these steps produces answers or solutions to questions or problems through direct action, trial and error, or experimentation. Such learning is also characterized as play (Birch, 1945; Fagen, 1976; Hutt, 1976; Petersen, 1988; Sylva, Bruner, and Genova, 1976).

Active Learning System

In Figure 1 the outer rectangle defines the boundaries of the Active Learning System (Carroll, 1982; Carroll, et al., 1985; Carroll & Rosson, 1987; van der Meij & Carroll, 1998). The large rectangles within enclose two subsystems, the Production System (Anderson, 1983, 1990, 1993; Gagne, 1964, 1966, 1985), representing the elements of the discovery process, and the Inquiry System, with its minimal online knowledge base containing concepts, rules, and facts, but not procedures.

One enters the active learning system without prior knowledge of the content of the learning task, but with general knowledge that can be called upon to help. Carroll, et al. (1985) observed repeatedly in their studies of adults learning computer systems, what has become a truism in the world of software publishing, that ". . . learners are overtly active in that they seem to prefer to learn by trying things out rather than by reading" (p. 284).

Play and Exploration

At the point of entry to a problem-solving learning environment, the learner faces an unknown experience with an uncertain outcome. "Psychic entropy"--cognitive disorder--characterizes one's experience on the threshold of the unknown (Berlyne, 1963; Csikszentmihalyi, 1988; Kubay & Csikszentmihalyi, 1990). The first steps that one must take are to find a way to reduce that initial uncertainty through one or both of the options available: by exploring the setting itself (the environment within which the problem exists) or by exploring the knowledge base, to begin to acquire knowledge of the setting, the situations or circumstances of the actors and characters within the environment, and the rules that govern the environment.

Task Identification

The purpose of “diversive” exploration (Berlyne, 1963) upon entering the active learning system is to reduce uncertainty (anxiety, entropy) through exploration and/or play. The goal of that stage is to identify a problem or puzzle to solve. This must occur before the production process begins. Identification of tasks or problems to solve is one of the most difficult and often frustrating phases in problem-solving. In the "real world," one may ask "What can I try to get this to work?" In the imaginary world of an adventure game a player may say "What can I do?" (which means, "What will this game allow me to do?").

Resource Acquisition

Resources are objects or tools needed to perform some action that is central to the enactment of a puzzle solution or production. All productions require at least one resource. If upon entering the learning system one chooses to explore the setting (the usual approach), one may acquire resources as they appear, or go straight to task identification. Task identification, resource acquisition, and diversive exploration are circular; one can do them in any order. It may be necessary to explore to find a resource after one has identified a task, or it may be possible to acquire a resource, either following the successful enactment of a production or before identifying the task for which the resource is needed.

Hypothesis Formation

Once a task has been identified, the nature of the exploring within the physical setting becomes focused on hypothesis formation; it changes to purposeful or "specific" exploration (Berlyne, 1963). Whereas the goal of diversive exploration is task identification, the goal of specific exploration is hypothesis formation. Hypothesis formation may involve additional specific exploration and knowledge base search and/or exploration until a hypothesis has formed. When a hypothesis is formed, it is tested immediately for discovery. In Hutt's (1976) view, having identified a task, the learner would shift from investigative exploration (e.g., of an object) to exploratory play, to make use of something to affect outcomes rather than continue to investigate and inquire about the possibilities for action.

Production System

The heart of the production system is a "production paradox": the learner's need to act in order to know versus the learner's need to know in order to act (Carroll & Rosson, 1987; van der Meij & Carroll, 1998). The production paradox, also called "the paradox of sense making" (Carroll, 1990), is the critical issue for those who do not succeed, because this paradox makes both action and guidance necessary for success. The knowledge available through each must be integrated in the learner's thinking for successful discovery of a production solution. The purpose of the production system is to enable the discovery and enactment of the procedure that accomplishes the enterprise task.

The term "enterprise" suggests the complexity of the production system beyond the stages shown in Figure 1. Enterprises are purposive activities that depend for their execution (successful enactment) on a combination of verbal information, intellectual skills, and cognitive strategies (Gagne and Merrill, 1990, p. 25). The production system outlined in the model shown in the figure, along with the component extensions of Gagne and Merrill's "enterprise schema," is what Gagne and Merrill would call an "enterprise scenario."

The Discovery Process

Gagne's formulation of the problem solving process as a synthesis of facts and rules into higher-order (production) rules (solution procedures) is also useful here. In fact Gagne (1964, 1966, 1985), Gagne & Merrill (1990), Carroll (1982, 1990, 1998), Carroll, et al. (1985), as well as Anderson (1983), McDaniel and Schlager (1990), and many others agree that discovery learning takes place when a learner creates a higher-order rule, principle (a general rule), or procedure (the expression or enactment of a general rule) from the combination of lower-order rules, facts, concepts, and sometimes procedures. This combination that results in discovery is represented by the production system in the model. A characteristic result of the discovery process is a superior kind of learning. As Gagne writes, "When this happens, the individually constructed higher-order rule is effective in generalizing to many situations and is, at the same time, highly resistant to forgetting" (1985, p. 193). Gagne argues (1964, pp. 293-294) that problem solving is itself a type of learning. When a problem is solved, a general rule is found (discovered, learned) for handling all similar situations. The discovery of that rule is the acquisition of new knowledge.

If the outcome of the test for discovery is negative, one returns either to (a) the inquiry system for more research, (b) to specific, purposeful exploration until a new hypothesis is formed; alternatively, (c) a new hypothesis may form immediately, from which one may seek confirmation in the knowledge base or the physical setting, or return directly to testing. If the outcome of the test for discovery is positive, the procedure is enacted (produced). A test of homeostatic certainty (negentropy, order) follows the enactment of a production system solution procedure. Failure of the certainty test means the concluding task has not been accomplished, and the process of identifying the next subtask begins. The successful enactment of a production is usually followed by acquisition of a new resource, both as reward and to enable future productions.

Enactment

Once formed, the hypothesis must be tested by "enactment" of the procedure (Gagne and Merrill use the term "manifesting"). If the hypothesis is correct, the attempt to perform the procedure will be successful and the problem solution will be enacted. The preparatory activities of the active learning process may be described in terms of task identification, play, (as both exploration and learning as defined by Berlyne, 1963), and resource acquisition. Inquiry and the elements of the production and enactment phase of the process are iterative. The outcome of the production phase of the process is the discovery of procedural knowledge that enables the correct enactment of some result, and it is dependent on the application of declarative knowledge in the active testing of hypothetical outcomes. To test hypotheses requires acquisition of resources necessary for such testing. The successful production of a problem solution through enactment occurs when the hypothesis formed is found to work (Anderson, 1983; Carroll, 1982, 1990, 1998; Carroll, et al., 1985; Gagne, 1964, 1966, 1985; McDaniel and Schlager, 1990). If hypothesis testing does not yield the correct result, the knowledge acquired consists of the elimination of an incorrect hypothesis, and no discovery or enactment occurs.

A Preliminary Test of the Model

In an innovative study of cognition and behavior that led either to success or failure in solving a popular computer-based adventure game (the learning task), only successful learners made appropriate use of the inquiry system by consulting the minimal knowledge base containing facts and rules that were essential to know to accomplish the goal but difficult or impossible to infer solely from exploring the task environment. Confidence, interest, and learning were greater for subjects who consulted the knowledge base when exploration as a means of task identification and hypothesis formation proved fruitless. Because only facts and rules could be acquired from the knowledge base, successful learners were required to discover and correctly sequence the problem solution procedures by reflecting on content acquired from studying both the task environment and the knowledge base.

The essential difference in performance between the learning and nonlearning groups, as well as the differences in performance between individuals, was the degree to which subjects understood the guided exploration learning model and applied it to the task. This suggests that understanding the underlying learning or instructional design model may be the most important factor affecting success with any learning task. The study also showed that a mixed method design and the use of an automated data recorder to collect video, think-aloud, and time-stream and intermittent questionnaire data simultaneously are powerful research techniques. Both the theoretical model and the results of the study suggest that an instructional knowledge base that moderates the uncertainties present in both real problem-solving situations and structured, problem-based learning environments is essential for success in problem solving and/or troubleshooting activities.

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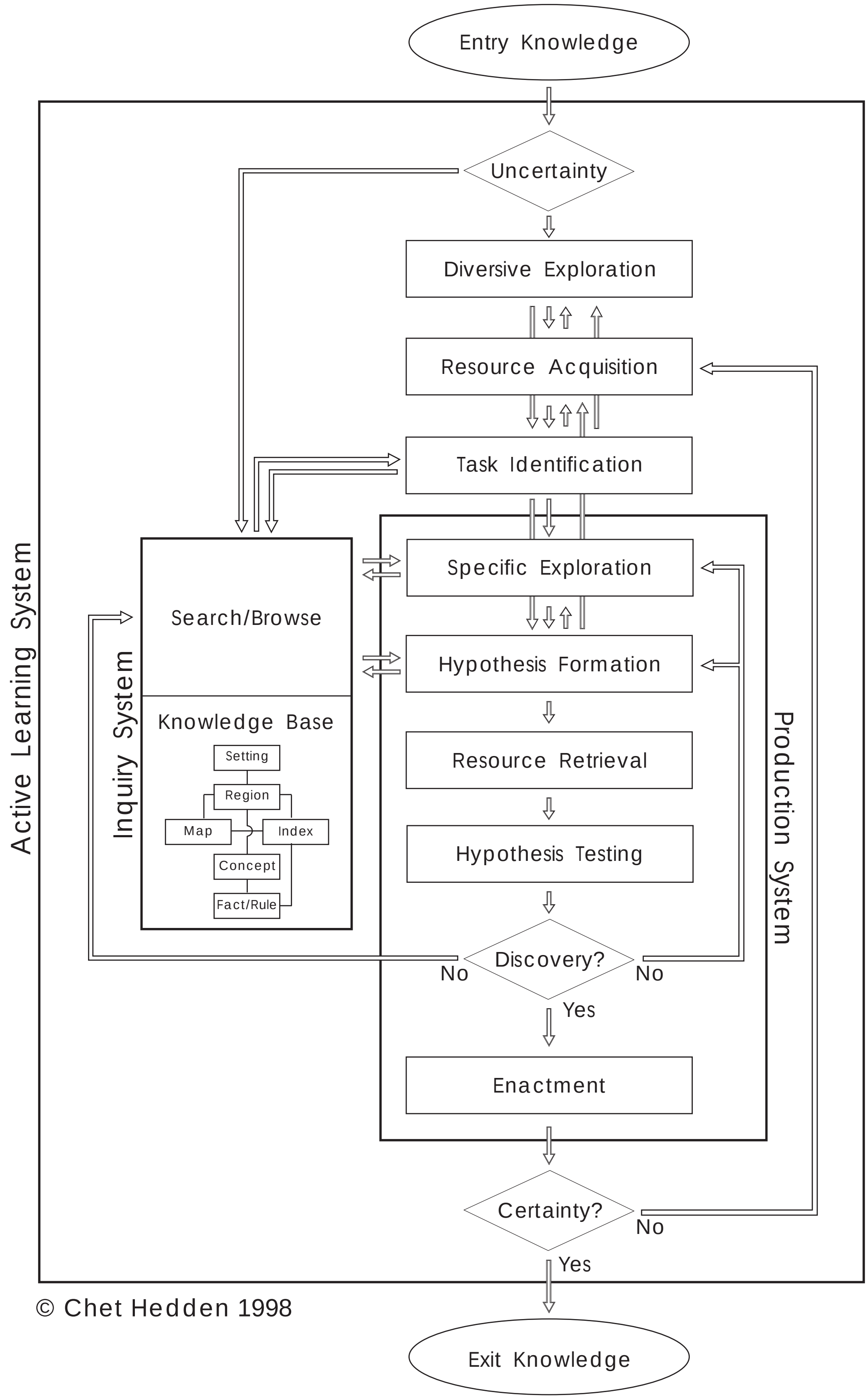

Figure 1: Guided Exploration Learning Model.