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ABSTRACT

A three-part study compared similarity-based learning (in which concepts are formed based on similarity among multiple examples) and explanation-based learning (in which general schema are acquired from a single example) in schema acquisition. Subjects, 16 undergraduates enrolled in introductory psychology courses at the University of Illinois and 4 paid subjects, participated in the first experiment; 30 students and 10 paid subjects participated in the second experiment; and 60 students participated in the third experiment. Subjects were asked in the first experiment to produce a general description of the schema, in the second experiment to generate another instance, and in the third experiment to answer yes or no questions about the schema. Results indicated that subjects could acquire a plan schema from a single example in knowledge-rich domains as predicted by the explanation-based approach. Results also indicated that subjects were not able to carry out explanation-based learning if they did not have sufficient domain knowledge and if the schema to be acquired was not structured by causal constraints. (Eight tables of data are included; 42 references are attached.) (RS)

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Technical Report No. 470

SCHEMA ACQUISITION FROM A SINGLE EXAMPLE

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Abstract

Three experiments were conducted to compare similarity-based learning and explanation-based learning in schema acquisition. Similarity-based learning approaches hypothesize that concepts are formed based on similarity among multiple examples. Explanation-based learning approaches hypothesize that a general schema can be acquired from a single example by connecting instantiations of existing schemata and generalizing the connected portion of the example. The present experiments demonstrated that subjects could acquire a plan schema from a single example in knowledge-rich domains as predicted by the explanation-based approach. These experiments also showed that subjects were not able to carry out explanation-based learning if they did not have sufficient domain knowledge and if the schema to be acquired was not structured by causal constraints.

SCHEMA ACQUISITION FROM A SINGLE EXAMPLE

Two contrasting trends have emerged in recent research on concept formation: similarity-based approaches and explanation-based approaches. Similarity-based approaches hypothesize that concepts are formed based on similarity among *multiple examples* (Murphy & Medin, 1985). Explanation-based approaches, which have appeared more recently, emphasize the role of prior knowledge in learning. Some models developed in the area of artificial intelligence hypothesize that *a single example* is sufficient to acquire a concept if a machine has sufficient domain knowledge (DeJong & Mooney, 1986; Mitchell, Keller, & Kedar-Cabelli, 1986). These models have had some success in dealing with machine learning, but there is no experimental evidence showing that humans can learn concepts based on a single example using explanation-based approaches. The present experiments demonstrated that subjects could acquire a schema from a single example in a knowledge rich domain while failing to acquire a schema from a single example in situations where they did not possess relevant domain knowledge.

Similarity-Based and Explanation-Based Learning

Similarity-Based Approaches to Concept Learning

Psychology. Many models of concept learning have been proposed which assert that similarity of features constitute the structural basis of categories (Wattenmaker, Nakamura, & Medin, 1987). These models place little if any emphasis on the role of domain knowledge in acquiring a concept. Most theories taking a similarity based approach were developed to account for the data from laboratory studies where the learning task involves the inductive learning of a simple concept from a large number of instances (Franks & Bransford, 1971; Posner & Keele, 1968, 1970; Reed, 1972).

In one class of similarity-based theories, prototype models, the features used for concept formation are assumed to be independent. But for more realistic concepts it is difficult to use central tendency of independent features as a way to represent a prototype because these concepts involve relationships between several concepts (Farah & Kosslyn, 1982). The problem of relational features led to the appearance of strength models (Anderson, 1982; Anderson, Kline, & Beasley, 1979; Elio & Anderson, 1981; Hayes-Roth & Hayes-Roth, 1977). For example, Anderson's ACT generalization model (Elio & Anderson, 1981) is a type of frequency model in which the frequency of occurrence of features and all their possible combinations determine the exemplar's representation. in this type of frequency model the generalization process occurs by finding *commonalities* between two productions and replacing the constants by variables.

Research in schema theory has generally focused on describing the structure of schemata. Much less attention has been devoted to the process of how schemata are acquired. However, the few discussions of the issue that occur in the schema literature tend to be frequency models (Rumelhart & Norman, 1978; Schank & Abelson, 1977, p. 227; Thorndyke & Hayes-Roth, 1979; Van Dijk & Kintsch, 1983). For example, Rumelhart has proposed three basic processes involved in schema acquisition; accretion, tuning, and restructuring (Rumelhart & Norman, 1978; Rumelhart & Ortony, 1977). Schema restructuring is the process involved in creating new schemata through either schema induction or patterned generation. Patterned generation is similar to learning through analogies and schema induction is a form of learning by contiguity. In particular, they state that "if certain configurations of schemata tend to co-occur either spatially or temporally, a new schema can be created, formed from the *co-occurring* configuration" (Rumelhart & Ortony, 1977, p. 46).

Artificial intelligence. In artificial intelligence, the traditional approach to learning has also been a similarity-based one. Many machine learning systems for concept acquisition learn new concepts by examining a large number of examples and counter-examples of a concept and then searching for a description in the representation language which includes all of the examples while excluding all of the counter-examples (see Dietterich, London, Clarkson, & Dromney, 1982; Dietterich & Michalski, 1983 for overviews of such methods; Mitchell, 1982). Much of the research in this area has involved developing methods for controlling this search and heuristically guiding it towards "simple" concept descriptions. Using toy trains as examples, Medin, Wattenmaker, and Michalski (1987) compared the biases and representational constraints of inductive learning systems to those exhibited by human

subjects performing inductive learning tasks. They found that like many machine learning systems, human subjects tend to adopt simple conjunctive descriptions.

Problems with Similarity-Based Learning

Similarity-based approaches to concept formation do not take into account the learner's prior knowledge, intentions, or goals. This approach may thus not give an adequate account of learning in knowledge rich domains. Recently the similarity-based approach to categorization has been criticized on a number of grounds (Medin & Wattenmaker, 1987; Murphy & Medin, 1985; Wattenmaker, Nakamura, & Medin, 1987). In particular, these investigators argue that the similarity-based approach is insufficient because there are no constraints on what features or correlations should be selected and no constraints on how features should be weighted depending on contexts. In artificial intelligence, similar issues have been raised suggesting that generalization acquired by similarity-based learning cannot be justified (Mitchell et al., 1986; Schank, Collins, & Hunter, 1986).

Similarity-based approaches have not taken into account the possibility that subjects can apply their prior knowledge in the active processing of exemplars. Most laboratory studies on concept formation or schema acquisition used simplified and artificial materials as stimuli (e.g., dot patterns or biographical descriptions of fictitious people). These kinds of exemplars could have prevented subjects from applying their prior knowledge, resulting in categorization strategies which may not be those used in natural settings. The behavior observed in these experiments may not be a simplification of more complex behavior but may involve a qualitatively different form of learning. Millward (1980) called letter strings, stylized faces, and dot patterns "pseudoconcepts" because there is no functional core. In other words, according to him, these concepts do not have any significance for subjects thus subjects cannot use their rich background knowledge in learning these concepts. Millward raises the possibility that different kinds of processes are used in learning pseudoconcepts compared to the learning of realistic concepts, such as rooms and restaurants.

Recently a number of experimental results have been reported which cannot be explained without taking into account the subjects' knowledge-based interpretation of the input stimuli. For example, Murphy and Medin (1985) have shown that people do not select any arbitrary correlation among features but they prefer causal correlations. For example, this study showed that people tended to relate the feature of dizziness to earaches rather than to weight gain. Medin, Wattenmaker, and Hampson (1987) showed that people abandoned undimensional sorting (i.e., sorting based on one dimension) in favor of sorting by correlated properties when features could be causally connected.

Example. In addition to these empirical findings, a concrete example of these processes can be seen in the following passage which was one of the experimental passages used. This example is about a cooperative buying scheme called *Kyeah* which is used in Korea.

> Tom, Sue, Jane, and Joe were all friends and each wanted to make a large purchase as soon as possible. Tom wanted a VCR, Sue wanted a microwave, Joe wanted a car stereo, and Jane wanted a compact disk player. However, they each only had $50 left at the end of each month after paying their expenses. Tom, Sue, Jane, and Joe all got together to solve the problem. They made four slips of paper with the numbers 1, 2, 3, and 4 written on them. They put them in a hat and each drew out one slip. Jane got the slip with the 4 written on it, and said, "Oh darn, I have to wait to get my CD player." Joe got the slip with the 1 written on it and said, "Great, I can get my car stereo right away!" Sue got number 2, and Tom got number 3. In January, they each contributed the $50 they had left for the month. Joe took the whole $200 and bought a Pioneer car stereo at Service Merchandise. In February, they each contributed their $50 again. This time, Sue used the $200 to buy a Sharp 600 watt 1.5 cubic foot microwave at Service Merchandise. In March, all four again contributed $50. Tom took the money and bought a Sanyo Beta VCR with wired remote at Service Merchandise. In April, Jane got the $200 and bought a Technics CD player at Service Merchandise.

Similarity-based learning theories do not provide a clear account of how learning could occur with a single example. In fact, they might predict that no generalization can occur from a single example. These approaches would not typically be able to use the explanatory structure of the example in the

generalization process. However, it seems to us that with materials such as that just given, people may be able to distinguish relevant and irrelevant features of the example from a single exposure and to abstract the general plan. If it can be shown that people can, in fact, generalize and abstract a concept from a single example, this serves as a fundamental problem for those approaches which assume that generalization occurs by noticing commonalities between multiple examples.

Explanation-Based Approach to Learning

Explanation-based approaches to learning emphasize the role of people's background knowledge in concept acquisition (Murphy & Medin, 1985; Wattenmaker, Nakamura, & Medlin, 1987). This prior knowledge provides explanations for how concepts are formed. Therefore, if people have enough domain knowledge, it should be possible to acquire a schema from even a single example by generalizing its explanation (Mitchell et al., 1986).

Recently, a group of researchers in artificial intelligence have developed models of concept formation in which domain knowledge plays an important role in constructing explanations that separate relevant features from irrelevant ones. These models emphasize that the system must be able to explain why the given example is an instance of the concept under study (Mitchell et al., 1986). The explanation process is very important for learning since it results in justified generalizations which avoids spurious correlation.

Learning in GENESIS. Based on an idea originally proposed by DeJong (1981), Mooney and DeJong (1985) developed a natural language system called GENESIS which uses explanation-based learning to improve its ability to understand natural language narratives by learning new plan schemata. Since the stimuli used in the current experiments are also narratives describing novel plan schemata, this particular system will be described in further detail.

GENESIS acquires a schema by explaining and generalizing a single specific instance of a plan performed by a character in a narrative. Established techniques in natural language processing (Schank & Riesbeck, 1981) are used to "understand" narratives by constructing explanations for the actions in the story. Characters' actions can be explained in terms of later actions which they enable or in terms of ultimate goals which they achieve. GENESIS constructs explanations by causally connecting instantiations of lower-level schemata from the system's current knowledge base. The resulting causal model of the narrative is similar to Johnson-Laird's mental model (1983) and Van Dijk and Kintsch's situation model (1983) in that it is a global representation of specific events and states.

When the system detects that a character has achieved an important goal (i.e., a goal arising from a known theme, Schank & Abelson, 1977) by combining actions in a novel and unfamiliar way, it generalizes the specific explanation for how the goal was achieved into a general plan schema. In the current GENESIS system (Mooney, 1988), generalization is performed by a general explanation-based learning technique called EGGS (Mooney & Bennett, 1986) which variabilizes the explanation and removes irrelevant information while maintaining the validity of the explanation. The resulting generalized explanation is then packaged into a schema and indexed so that it can be subsequently retrieved and used for future narratives.

Genesis' operation is best illustrated by an example. Consider the case in which GENESIS learns a schema for someone murdering another individual in order to inherit their wealth. Before processing a narrative which describes a specific instance of this schema, the system has schemata for murdering and for inheriting; however, it does not have a schema for "murder for inheritance." The specific explanation the system constructs for this narrative allows it to answer a number of questions about why characters performed the actions mentioned in the text. Also, by generalizing this explanation, GENESIS learns a new schema which it calls "MurderInherit" based on the names of the existing schemata which compose it. The learned schema is characterized by a set of variables or slots (which are indicated by a leading "?" [e.g., ? x 1]) and by a set of constraints which specify necessary properties and relationships of these variables and actions in which the variables take part. For example, the murderer (?a5), the victim (?d1), and the inherited item (?o4) are all variables of the new schema and the fact that ?a5 is the heir of ?d1 and that ?or is valuable are constraints. Below is the actual input/output trace produced by the system for this example:

Input: Claudius was Agrippina's husband and owned an estate.
Agrippina gave him a poisonous mushroom and he died. She inherited the estate.
Thematic goal achieved: Agrippina is happy that Agrippina has the estate.
Explanation suitable for generalization.
Pruning .. Generalizing ... Packaging ... Creating New Schema: (MurderInherit ?a5 ?o4 ?d1)
?a5 is a character. ?d1 is a person. ?a5 murders ?d1. ?or is an inanimate object. ?or is a valuable. ?d1 has ?or. ?a5 is ?d1's heir. ?a5 inherits ?d1's ?o4.
Having: ?a5 murdered ?d1. Suggest MurderInherit
Ready for questions:
>Why did Agrippina give Claudius the mushroom?
So Claudius would eat the mushroom and so Claudius would die.
>Why did Claudius eat the mushroom?
Because Claudius was hungry.
>Why is Claudius dead?
Because Agrippina poisoned Claudius with the mushroom.
>Why did Agrippina kill Claudius?
So Agrippina could inherit Claudius's estate.
>Why did Agrippina inherit the estate?
Because Claudius was Agrippina's husband, because Claudius had the estate and because Agrippina poisoned Claudius with the mushroom.
>Why is Agrippina Claudius's heir?
Because Claudius was Agrippina's husband.

The newly learned schema is added to the system's existing knowledge base where it can be used to aid in the understanding of subsequent narratives. A complete technical description of GENESIS and the general EBL mechanism underlying it (EGGS) is presented in Mooney, 1988.

Problems with Explanation-Based Learning

A system based on explanation can only function effectively when it has sufficient knowledge about the domain and the schema to be learned is organized by causal constraints. Therefore, explanation-based learning should not occur for domains in which the understander does not have sufficient knowledge to provide an explanation for why certain features are relevant for the schema. However, explanation-based approaches do not make a clear prediction about what people do when they want to learn a new schema and have insufficient knowledge to construct an explanation.

In particular, explanation-based systems provide no mechanism for making use of similarities across multiple examples. Lebowitz (1986) suggested integrating similarity-based and explanation-based learning. His UNIMEM system stores all the specific examples without making any generalization and looks for commonality among these specific instances. If it finds one, it tries to construct an explanation for the commonality. More recent work in this area has focused on using explanation-based learning to select relevant features for a similarity-based learning system (Danyluk, 1987). However, neither of these systems have been interpreted as psychological models of learning.

Overview of Experiments

The following three experiments tested both the psychological validity of explanation-based learning and its limitations. Each experiment had two conditions, an explanation-based learning condition (EBL) and a non-EBL condition. The EBL conditions made use of plan schemata in knowledge-rich domains and tested whether or not subjects could acquire an abstract schema from a single example. It was predicted that subjects would be able to acquire a schema from a single example if they have sufficient domain knowledge and if the schema is determined by causal constraints. The non-EBL conditions examined schema acquisition with materials where the subjects did not have appropriate background knowledge to use explanation-based learning. For this condition, it was predicted that the subjects would not be able to use explanation-based learning to acquire a correct schema in a single trial. For each experiment, a different task was used to test whether or not subjects had formed a schema from a single instance.

Conditions and Schemata Used in the Experiments

The EBL condition. The three schemata to be learned by the subjects in the EBL conditions were selected with the following restrictions. First, major constituents in each schema were causally related in terms of an important goal. In other words, the underlying schema was a "plan" schema in which characters try to achieve a goal (Schank & Abelson, 1977). Second, the schemata were selected to be composed of elements that undergraduate subjects could understand and explain using aspects of their existing knowledge. Third, the schemata were chosen to be ones not already known by undergraduate subjects. To insure that this last condition was met, the subjects were asked, after the completion of each experiment, whether they had previously heard of any of the plans described in the passages. The data for subjects who stated that they had heard of any of the plans were discarded.

Three different schemata were selected which met these criteria: (a) A cooperative buying scheme that is used in several nonwestern cultures; (e.g., in Korea the system is called "Kyeah" and in India it is called a "chit fund" (see the earlier section for an example of this schema); (b) a technique used by art thieves for making additional money by fencing copies of a stolen collectable; (c) a confidence game known as the "phony bank-examiner ploy" (Wharton, 1967).

The non-EBL condition. A different set of criteria were used to select the schemata for the non-EBL conditions. First, the schemata were selected to be ones with a goal that was not likely to be known by American undergraduate subjects. With a schema of this type it should be difficult for subjects to construct a coherent causal model. Second, the schemata were selected to contain some un-explainable components such as social conventions for which explanations and causal models are not appropriate. Third, the schemata were chosen to be ones for which subjects did not have a pre-established schema.

Using these criteria, two schemata were selected for the non-EBL conditions: (a) A potlatch ceremony carried out by certain North American Indians in which hosts of the potlatch give away valuables to improve their status; and (b) a traditional Korean wedding ceremony which has many conventional actions quite different from Western ones.

Schema Learning Tests

Three tasks were developed to measure the degree to which subjects were able to acquire a schema from a single instance. The tasks were (a) producing a general description of the schema (Experiment 1), (b) generating another instance (Experiment 2), and (c) answering yes/no questions about the general schemata (Experiment 3). In Experiment 1, subjects were asked to generate a general description (schema) of the specific instance they read. Experiment 2 tested how well subjects could generate new instances of a schema. Schema processes are presumed to be generative, where generative means a process that can deal with an infinitely large number of new instances (Bartlett, 1932; Rumelhart, 1980). Therefore this task is an additional way of testing the quality of a schema acquired from a single example. However, the tasks used in Experiments 1 and 2 may not give a full picture of what subjects had learned because these tasks require subjects to write down a complete account and they may not choose to write down everything they have learned. The use of discourse conventions (Grice, 1975) may lead subjects to omit obvious components of the schema. Therefore in Experiment 3, subjects were asked direct yes/no questions about all the constraints and variables of the schema to be acquired.

Criteria for Correct Schema Acquisition

The present experiments employed the constructs of constraints and variables as a criterion to judge how well subjects acquired the schema from the passage they read. For example, in the *Kyeah* schema described in the earlier section, the participants, the amount of money, etc., are variables while the statement that "the method should be fair to all the participants' is a constraint. If subjects acquired the correct schema, they should be able to recognize which aspects of the underlying schema were constraints and which were variables. It is important to note that unlike most concept formation experiments, the criterion for how well subjects formed the concept is not based on independent

attributes or features but on the variables and constraints which specify the relational properties of the concept.

Instance Versus Abstract Input

Experiments 2 and 3 involved two groups; (a) an instance group which received a specific instance of the schema; and (b) an abstract group which was directly taught the content of the schema through a direct abstract description of it. In all of the experiments, the instance group was given only a single instance of the schema. Thus any learning that occurred in this group would be outside the domain of learning theories which required multiple instances. The abstract group was given explicit information about the schema, so if the instance group performs as well as the abstract group on a task requiring knowledge of the general schema, then it is assumed that the subjects in the instance group had also acquired the schema. Table 1 provides an overview of the experiments.

[Insert Table 1 about here.]

Experiment 1: Abstract Descriptions

Experiment 1 investigated whether subjects could acquire a schema from a single instance by giving them a single instance and asking them to write a general abstract description of the schema.

Method

Materials

An instance passage was developed for each of the EBL and the non-EBL schemata described in the earlier section.

EBL instance. In the instance passages for the EBL condition, all of the variables were instantiated so that there were specific names for the characters (e.g., Tom, Mr. Miller), specific dates, and so on. Also, the passages contained specific instantiations of all the constraints of the schema, such as the goals of the plans (e.g., "Participants want items which they cannot afford" in the Kyeah schema) and the methods used to achieve the goals (e.g., "Each participant donates small amount of money at particular intervals" in the Kyeah schema). One of the EBL instance passages was given in the Introduction.

Non-EBL instance. In the instance passages for the non-EBL condition, all the variables were instantiated but these passages differ from those for the EBL condition in that the goal or the motivation of actions (e.g., "improving a chief's status by giving away valuables" in the potlatch schema) was *not* included; they would not provide the knowledge required for explanation-based learning. An example of one of the non-EBL passages follows:

> Yanagi is a Kwakiutl chief and a descendent of Monaga. One day, Yanagi decided to hold a potlatch and invited Kaoka, a chief of a tribe whose ancestor is Monaga, and four of his followers. Yanagi's family gathered fresh and dried fish, berries, and animal skins. On June 6th, the appointed day, the guests paddled up to the host's village and went into Yanagi's house. There they gorged themselves on salmon and wild berries while dancers masked as beaver gods entertained them. While Yanagi's wife and daughter-in-law wearing seashell necklaces were busy serving food to the guests, Yanagi and his cousins, Egulac and Hiipe, arranged the wealth they had gathered in neat piles. Kaoka, the guest chief, stared at Yanagi as Yanagi danced up and down, telling the visitors about how much he was about to give them. As he counted out the boxes of berries and fish, Yanagi said Kaoka was poor. Yanagi's followers said "Do not make any noise, tribes. Be quiet or we shall cause a landslide of wealth from our chief, the overhanging mountain." At the climax of the potlatch, Yanagi and his first son, Managi, stood up and started burning animal skins. Yanagi's wife, hugging her son, watched their destruction. Finally, Yanagi, Joam, and Hiipe gave the remaining piles of gifts to Kaoka and his first son. Laden with gifts, the guests paddled back to their own village.

Prior to the experiment, a list of constraints and variables was prepared by analyzing each schema within the framework outlined earlier. (See Table 2 for the complete lists of constraints and variables for the Kyeah and Potlatch schemata.)

[Insert Table 2 about here.]

Subjects

Sixteen undergraduate students at the University of Illinois participated in the experiment in partial fulfillment of a course requirement for introductory psychology and there were four paid subjects. The paid subjects were distributed across the experimental conditions.

Design and Procedure

Each subject was given instance passages and was told for each one to "write, in abstract terms, a description of the general technique illustrated in the narrative." Ten subjects received the three EBL instance passages and 10 subjects received the two non-EBL instance passages.

In order to make sure the subjects understood the instructions, they were given a sample narrative and an appropriate abstract description. This example narrative was included to show subjects what level of abstraction was expected. The demonstration narrative was about skyjacking and was selected to be unrelated to the schemata used in the experimental passages. The demonstration passage did not provide any specific information that could be used in determining which aspects of the experimental passages were variables and which were constraints. A correct analysis of the instance passages could only be carried out by the reader providing an explanation for the individual instance. For example, in the demonstration passage, an airplane was mentioned in both the demonstration narrative and its corresponding general description since it was a constraint of the skyjacking schema. In one of the experimental passages (*Kyeah*), a VCR was mentioned, yet, it was not a constraint in the Kyeah schema and so should not be incorporated in the general description.

After reading the instructions, all of the subjects read the first passage, wrote a general description for it, and continued, in the same fashion, with the remaining passages. Subjects were allowed to work at their own pace. All the subjects read the passages in the same order. Subjects were allowed to refer to the appropriate instance passage while they were writing the general description. After finishing the experiments, subjects were asked whether they had previously heard of any of the techniques described in the passages. In both conditions, no more than two subjects said they had heard of a similar technique and the data from these subjects were discarded, giving a total of 10 subjects in each condition.

Scoring Methods

Each constraint and each variable in the schema was scored as either: correctly mentioned (C), incorrectly mentioned (I), or omitted (O). The scoring criteria for variables and constraints were as follows: A variable was considered to have been identified if an abstract term, such as "group" or "something," was used to refer to it. However if the subject's description retained the specific constant used in the instantiated passage, it was scored as incorrect. A constraint was scored as correct if the subject's description contained a statement consistent with the pre-established list. A constraint was scored as incorrect if the subject's description contained a statement inconsistent with any constraint in the constraint list. For example, in the Kyeah schema, the statement, "the order of getting money is decided by the most powerful person in the group" would have been scored as incorrect since it was inconsistent with the constraint, "order must be assigned randomly."

Two judges independently scored the constraints and variables for the data from five randomly sampled subjects using the established list of constraints and variables. The percentage of agreement between the two judges was 87%. Since the reliability of the scoring was reasonably high, the scores from one of the judges were used for the final analysis.

Depending on how the omitted constraints or variables are treated, there are several possible ways to calculate the percent correct from the three types of response scores. In the present study, omitted constraints were considered to be incorrect. In other words, the percent correct for constraints was the number of items correctly mentioned out of the total number of constraints [C / (C+I+O)]. This method is more conservative than one which ignores omissions and calculates the percent correct based on only the items explicitly mentioned [C / (C+I)]. The subjects could have omitted some constraints simply because they were lacking motivation, or because they assumed these constraints were implied in their descriptions. So the scoring method used in this study will probably be an underestimate of the actual amount of schema acquisition on a single trial.

However, for variables, the logic for how to score omits reverses. In communicating, people frequently leave out unimportant components such as the variables (Grice, 1975). Thus, counting "omits" as errors is conservative. One could argue that the subjects knew the omitted variables and should be given credit for the omits [(C+O) / (C+I+O)]. However, instead of using this liberal method, omissions were ignored in the present analysis and the percent correct for variables was calculated based on only the items explicitly mentioned [C / (C+I)].

Results and Discussion

In the EBL-condition, 74.9% of the constraints were explicitly mentioned in the subjects' general descriptions. However, in the non-EBL condition, only 18.1% of the possible constraints were correctly mentioned in the subjects' general descriptions. In the EBL condition, subjects identified 89.3% of the variables while those in the non-EBL condition identified 75.4%. Table 3 gives the data for each individual schema in each condition.

[Insert Table 3 about here.]

In addition to the strict scoring, it is also interesting to examine the data on omits. The subjects in the EBL condition omitted only 24% of the constraints and 32.9% of the variables while those in the non-EBL condition omitted 74.6% of the constraints and 66.1% of the variables.

> An example of one of the descriptions of the Kyeah schema in the EBL condition follows. Variables are indicated by a V and by a number which corresponds to the relevant variable in Table 2. Correct constraints are indicated by a C and by the corresponding constraint number from Table 2: Suppose in a group of people (V2, V4) each person would like to buy something expensive (V1, C7), but over a period of time (V3), each person cannot earn enough to buy what he would like (C1). By using random selection (V8, C2), each person could be assigned a number. When the group had saved enough money (V5, C5) together (C6) to purchase an item (C3), the person with the first number would get his item. This would continue for the rest of the group until everyone had gotten what he wished (C3).

In this description, six variables (V1, V2, V3, V4, V5, and V8) were correctly identified, two variables (V6 and V7) were omitted, and none of variables were treated as constants by the subject. Also, seven constraints (C1, C2, C3, C5, C6, C7, and C8) were judged to be correctly mentioned and two constraints (C4 and C9) were omitted.

An example of a general description written by one of the subjects for the potlatch schema in the non-EBL condition follows. Variables are indicated by a V and by a number which corresponds to the relevant variable in Table 2. Correct constraints are indicated by a C and by the corresponding constraint number from Table 2:

> If someone (C1) wanted to honor a relative of theirs (C3, C4), they would invite them (V1) over and give them gifts (V3) and food (V4). They would try to collect as many gifts to give as they could and make sure the visitors were happy (C6) and comfortable with food and entertainment. Before the visitors left they would be given as much as they could take home with them to show their love for their relatives.

In this subject's description, three variables (V1, V3, and V4) were scored as correct and no variables were retained as constants. One constraint (C4) was scored as correct, three constraints (C1, C3, and C6) were scored as incorrect, and the remaining three constraints (C2, C5, and C7) were omitted.

The results of the EBL condition in Experiment 1 showed that individuals are able to form correct schemata from single examples. The subjects were fairly successful at forming plan schemata from single examples as measured by their abilities to write a general description. However, the performance of the subjects in the non-EBL condition was very poor. They obeyed fewer constraints and omitted more constraints and variables from the schemata.

Experiment 2: Generating New Instance

Experiment 2 investigated schema acquisition by examining the ability of subjects to generate a new instance of a schema after having been exposed to a single original instance. It was predicted that in the EBL condition, there would be little or no difference between the instance group and the abstract group while in the non-EBL condition, the performance of the instance group would be much lower than that of the abstract group.

Method

Materials

An abstract description designed to give explicit information about the schema was developed for each of the schemata in the EBL and the non-EBL condition. In the abstract passages, the content of each schema was described in general terms. No specific instances were mentioned in the abstract passages and all the variables were mentioned in general terms such as "a number of people" instead of "4 people," and "at a regular interval" instead of "every month," and so on. For the three schemata in the EBL condition, all the constraints including the goal of the plan and methods of achieving the goal were given in general terms. Following is the abstract passage for the Kyeah schema:

> Suppose there are a number of people (let the number be n) each of whom wants to make a large purchase but does not have enough cash on hand. They can cooperate to solve this problem by each donating an equal small amount of money to a common fund on a regular basis. (Let the amount donated by each member be m.) They meet at regular intervals to collect everyone's money. Each time money is collected, one member of the group is given all the money collected ($n \times m$) and then with that money he or she can purchase what he or she wants. In order to be fair, the order in which people are given the money is determined randomly. The first person in the random ordering is therefore able to purchase their desired item immediately instead of having to wait until they could save the needed amount of money. Although the last person does not get to buy their item early, this individual is no worse off than they would have been if they waited until they saved the money by themselves.

For the two schemata in the non-EBL condition, all the cultural conventions in the ceremony and all of the explanation including the goal and procedures of the ceremony were given explicitly in the narrative. However, the non-EBL schemata contained a number of actions and objects which are cultural conventions and thus have no causal explanation. For these aspects of the ceremonies it was not possible to provide an explicit explanation (e.g., why, by custom, a bridegroom gives a wooden goose to a future father-in-law). Still in the abstract passages for the non-EBL condition, all of these non-causal actions and objects were explicitly described as constraints. Following is the abstract passage for potlatch schema:

> One of the most famous of the institutions described by ethnographers is the potlatch ceremony of the native Indians of the northern Pacific Coast of North America. Potlatching tribes included the Coast Salish of Washington and British Columbia and the Kwakiutl, who live farther north. The potlatch was generally a festive event. When the chief of a tribe is not content with the amount of respect he was getting from his own followers and from neighboring chiefs, he held a potlatch. The family titles to which the chief lays claim belong to his ancestors, and there are other people who can trace descent from the same ancestors and so they were entitled to vie with

him for recognition as a chief. Every chief therefore feels the obligation to justify and validate his chiefly status. The prescribed manner for doing this is to hold a potlatch. Each potlatch is given by a host chief and his followers to a guest chief and his followers. The object of the potlatch is to show that the host chief is truly entitled to chiefly status and that he is more exalted than the guest chief. To prove this point, the host chief gives the rival chief and his followers quantities of valuable gifts. The sponsor's prestige grows directly with the magnitude of the potlatch, the volume of goods given away in it. The guests' status is reduced by receiving gifts but they have no choice but to receive the gifts. During the ceremony, various kinds of food are served while dancers masked as several gods entertain the guests. Sometimes, the host chief destroys the valuables in front of the guests.

Subjects

Thirty undergraduate students at the University of Illinois participated in the experiment in partial fulfillment of a course requirement for introductory psychology and there were 10 paid subjects. The paid subjects were distributed across the experimental conditions.

Design and Procedure

Twenty subjects (the instance group) were given the instance passages and 20 subjects (the abstract group) were given the abstract schema descriptions. Within each group, 10 subjects were in the EBL condition and 10 subjects were in the non-EBL condition. Subjects in the EBL condition received the three EBL passages and those in the non-EBL condition received the two non-EBL passages.

Both groups were given instructions asking them to generate another instance of the technique described in the passage. The actual instructions for two groups were slightly different because of the differences in the types of materials read by the groups. Subjects in the instance group were told that for each experimental passage, they were to "write another story in which characters use the general method illustrated in the story but that is otherwise as different as possible." Subjects in the abstract group were told that for each passage, they were to "write a story in which particular individuals use the technique described in the passage in a specific case." Besides the instructions, the procedure was the same as in Experiment 1.

Scoring Method

The scoring method used in this experiment was the same as that described for Experiment 1 except for the following changes. In this experiment, variables were scored as correct if the subjects changed the value of the variables given in the instance passage (e.g., "three people" instead of "four people"). But if the subjects' description retained the specific variable used in the instance passage, it was scored as incorrect as in Experiment 1. In the abstract group no score for variables was possible because there were no constants to variabilize in their passages (e.g., number of participants, items purchased, etc.).

As in Experiment 1, two judges independently scored the data from five subjects' responses. There was 91.8% agreement between the two judges. Given this high degree of agreement, the final results were based on the data scored by one of the judges.

Results and Discussion

In the EBL condition, the average percent correct for constraints in the instance group was 78.8% while it was 73.6% for the abstract group. In the non-EBL condition, the average percent for constraints in the instance group was only 11.4% while it was 61.0% for the abstract group. Table 4 gives the percentages for each individual schema.

[Insert Table 4 about here.]

There was no difference between the two conditions in the number of changed variables. The instance group in the EBL condition correctly changed 66.3% of the variable items and the instance group in the non-EBL condition correctly changed 72.9%. However, the instance group in the non-EBL condition

omitted 61.1% of the variables while the instance group in the EBL condition omitted only 20.8% of the variables.

An example of a new instance of the Kyeah schema written by a subject in the instance group of the EBL condition follows. Variables are indicated by a V and by a number which corresponds to the relevant variable in Table 2. Correct constraints are indicated by a C and by the corresponding constraint number from Table 2.

> Bill, Kim, John and Mary (V2, V4) were all business associates (C9). Bill wanted some land in northern Illinois, Kim wanted a new house in Switzerland, John wanted a new Porsch 928S with all accessories, and Mary wanted to take a trip around the world (V1, V7, C7). The only problem was they each only had $25,000 (V6, C5) left unspent at the end of each month (V3, C1). They all got together and picked random variables on Bill's business computer (V8, C2). Mary was farthest from her variable so she would have to wait till last to get her trip around the world. John nailed his variable and jumped enthusiastically saying, "Yeah, I get to get my new Porsch 928S right now." They each talked with their banker and drew the $25,000 out (C4) and pooled it together (C6) after the first month (V5) and the next day John drove up in his new, black, 928S with all accessories (C8). At the end of the next month they again pooled their money and Kim got her chalet in Switzerland. Again at the end of the next month they pooled their money and Bill got his land in northern Illinois. Finally, after the fourth month they pooled their money together and Mary left for her trip around the world (C3).

In this description, six variables (V1, V4, V5, V6, V7, and V8) were correctly identified and two variables (V2 and V3) were treated as constraints. All nine constraints were judged to be explicitly mentioned and thus scored as correct.

An example of a new instance of the potlatch schema written by a subject in the instance group of non-EBL condition follows. Variables are indicated by a V and by a number which corresponds to the relevant variable in Table 2. Correct constraints are indicated by a C and by the Corresponding constraint number from Table 2.

> Joan decides to have a family reunion (C1, C3) and invites many of her distant relatives (V1, C4). One of which is John. So John and his family go to Joan's house on June 23 (V2), the day of the party. John and his family ate and mixed with the rest of the relatives. Then Joan began walking around talking about the wealth of individuals at the party and when she got to John, she said that he was poor. Then she began to throw food (V4) away and when she was done she gave John and his family the left-overs (V3). John and his family left with the food.

In this description, four variables (V1, V2, V3, and V4) were scored as correct, no variable was scored as incorrect, and five variables (V5, V6, V7, V8, and V9) were omitted. One constraint (C4) was judged as correctly mentioned, two (C1 and C3), incorrectly mentioned, and four constraints (C2, C5, C6, and C7) were omitted.

The results of Experiment 2 showed that in the EBL condition, subjects given a single instance of a schema generate new instances as well as the subjects overtly given the abstract schema. However, in the non-EBL condition, subjects given a single instance were not very successful in generating new instances of the schemata compared to the performance of the subjects overtly given the abstract schema. The non-EBL instance group omitted more variables and mentioned more incorrect constraints than the abstract group.

Experiment 3: Yes/No Questions

Experiment 3 investigated schema acquisition from one instance by asking subjects a series of explicit questions about the schemata. In Experiments 1 and 2, it is possible that the subjects did not make the effort to change the values of all the variables and to mention all the constraints in their written texts even though they had, in fact, acquired the appropriate information. Experiment 3 directly tested the subjects' understanding of all of the variables and constraints by asking yes/no questions about each of the constraints and the variables in each schema.

Method

Materials

The passages used in this experiment were the same as those used in Experiment 2 (i.e., the instance and the abstract versions of the schemata in the EBL and the non-EBL conditions).

A set of yes/no questions was developed to test the constraints and variables for each schema. For each constraint or variable in a given schema, there was one corresponding question. For the constraint, "Each participant donates the same amount," the question was "Can some people consistently donate less than others and have the system work? (correct response--no)" For the variable, "Number of participants does not matter," the question was "Is there any particular number of people required for this plan? (correct response--no)" In the EBL condition, there were 46 questions about the constraints and 46 questions about the variables. (See Ahn, 1987 for the complete set of questions.) In the non-EBL condition, there were 23 questions about the constraints and 18 questions about the variables. (See Ahn, 1987 for the complete set of questions.) None of the questions referred to specific situations from the example passage and all the questions were written in general terms so that the same questions could be used for individuals who had read both instance and abstract passages. The expected answer was "yes" for half the questions and "no" for the other half.

Subjects

Sixty undergraduate students at the University of Illinois participated in the experiment in partial fulfillment of a course requirement for introductory psychology.

Design and Procedure

There were two experimental groups in this experiment (an instance group and an abstract group) and two conditions (an EBL and a non-EBL condition). Each group received a booklet containing one of the appropriate sets of passages. Thirty subjects received the instance passages (instance group) and 30 subjects received the abstract passages (abstract group). Fifteen subjects in each group received the three EBL passages and 15 in each group received the two non-EBL passages. The same yes/no questions were used for both groups within each condition.

Both groups were asked to answer the questions about each narrative with "yes" or "no" and to justify their answers for each question. Besides the instructions, the procedure was the same as in Experiment 1.

Results and Discussion

The data were scored according to the pre-established criteria which would be expected as a result of a full understanding of the schema. In the EBL condition, the average overall percent correct for the instance group was 85.4% and that for the abstract group was 81.1%. There was no significant difference between the two groups, $t(28) = 1.62$, $p > .10$. In the non-EBL condition, the average percent correct for the instance group was 58.5% and that for the abstract group was 86.2%. There was significant difference between the two groups, $t(28) = 10.49$, $p < .001$.

For the questions about variables, in the EBL condition the percent correct for the instance group was 84.7% and that for the abstract group was 79.3%. This difference was not significant, $t(28) = 1.40$, $p > .10$. For questions about constraints, the mean score for the instance group was 86.1% and the mean for the abstract group was 82.7%. This difference was also not significant, $t(28) = 0.8315$, $p > .10$. However, in the non-EBL condition, for both variable and constraint questions, the percent correct for the abstract group (85.6% and 86.7%, respectively) was higher than those for the instance group (55.6% and 59.4%, respectively), $t(28) = 5.77$ and $t(28) = 6.6185$, $p < .0001$. Table 5 contains the percent correct for each narrative.

[Insert Table 5 about here.]

In the EBL condition, an examination of the subjects' justifications for incorrect answers showed that most of the "errors" were not due to the subjects' failure to generalize in an explanation-based manner but were due to the subjects' generating a schema slightly different from the one that the text was intended to convey. Some of the yes/no questions made assumptions about the execution of the plan which could be relaxed to generate an even more general schema. Within those answers scored as incorrect, 54[illegible]% of the example group's justifications and 52.9% of the abstract group's justifications presented arguments which were based on a causally consistent interpretation of the schema. For example, for the question, "In the above plan, is it necessary that the number of meetings be the same as the number of people in the group?" one subject responded "No" and then justified the answer by writing, "it's irrelevant. They could collect money every week and then at the end of the month the one person gets it all." This individual clearly understood the constraint but used this knowledge to answer the yes/no question differently than the preestablished answer. An example of a causally inconsistent justification can be seen in one subject's response to the question, "Is there any particular number of people required for this plan?" The subject answered, "Yes, four is the only number of people that will make this plan work."

In the non-EBL condition, among those items marked as incorrect, 3.1% of the instance group's justifications and 8.0% of the abstract group's justifications presented arguments which were consistent with the schema. These low percentages in both groups are probably due to the opaque or the non-causal aspects of the non-EBL schemata, which made it difficult for the subjects to develop alternative explanations.

In general, the results of Experiment 3 showed that for the EBL condition, there was no difference between the instance group and the abstract group in their understanding of the variables and constraints in the schemata. Thus this experiment provided strong evidence that subjects given a single instantiated schema in the EBL condition can acquire the underlying schema as well as a group given explicit information about the schema. However, in the non-EBL condition, subjects in the instance group were much worse at answering yes/no questions about the non-EBL schema than was the group given explicit information about the schema.

Besides the comparison of overall percent correct in each group and each condition, an analysis of the percent correct for each variable and constraint was carried out for the non-EBL condition. The analysis showed that there were large differences between the abstract group and the instance group in the scores for specific questions. Tables 6 and 7 list the questions for which the difference in percent correct between the two groups was larger than 30%. These questions could largely be grouped into four categories; (a) schema goals, (b) specific domain knowledge, (c) non-causal components and schema assimilation not a category but a type of response within the categories, (d) unfamiliar variables.

[Insert Tables 6 & 7 about here.]

Schema Goals

The instance group was not able to answer questions related to the goal of the potlatch schema (i.e., "improving a chief's status"). They did not understand the culture of the Northwest American Indians so they could not comprehend the chief's goals. However, in the case of the Korean wedding ceremony schema, subjects could easily identify the goal of the ceremony (i.e., two people getting married) from the instance passage even though it was not stated. For this schema there were not large differences between two groups in the questions related to the goals of the main actors. It appears that knowledge about schema goals is one important component that allows explanation-based learning for narratives that describe intentional actions.

Specific Domain Knowledge

Questions requiring relatively specific domain knowledge caused large differences between the instance group and the abstract group on certain items. In the potlatch schema, for example, the subjects did not know that "The tribes that carry out potlatch ceremonies are American Indians living in

northwestern America." Therefore, they could not develop an explanation for the story based on the different value system of those American Indians. Similarly, for the Korean wedding ceremony schema, the subjects did not know that "A bridegroom and a bride should be strangers until the day of a wedding ceremony." Subjects who are missing specific domain knowledge may find it difficult to develop consistent causal relationships for the events in the passage.

Non-causal Components

The Korean wedding ceremony schema contained a number of conventional actions. For example, in a Korean wedding ceremony, it is necessary that a bridegroom give his future father-in-law a wooden goose before the ceremony and that the bride should wear a blue dress. These actions are simply traditional parts of the ceremony and cannot be causally related to the goal. The instance group did not realize that these components were non-causal constraints and tended to treat them as variables.

Unfamiliar Variables

The instance group was able to identify the variables in the non-EBL passages which are also frequently variables in other schemata (e.g., date of ceremonies or colors of clothing). However, there was a large difference between the instance group and the abstract group for the questions about unfamiliar variables. The subjects knew that the ceremonies were part of another culture so they might have been biased to treat unfamiliar variables as constraints. For example, more than half of the subjects in the instance group thought it was necessary for the bridegroom to pass under the oldest tree in the bride's village, which is, in fact, a variable.

Schema Assimilation

For some of the items it is obvious that the subjects attempted to use their background knowledge to carry out explanation-based learning and where the background knowledge did not match the structure of the experimental schemata they made many errors. In the instance passage, describing the Korean wedding ceremony schema, the bridegroom brought two rings. The subjects used their knowledge of western weddings and mistakenly considered this variable to be a constraint. In fact, on this item, the percent correct for the instance group (20%) was considerably below chance level. Therefore, this data suggest that even in the non-EBL condition, the subjects were trying to interpret the instance in terms of their prior knowledge, and this process could result in dramatic misunderstanding of a new concept in domains where they do not have appropriate background knowledge.

General Discussion

Comparison Between the EBL Condition and the Non-EBL Condition

The results from these experiments suggest that subjects could acquire a general schema from a single example in a knowledge rich domain. An overview of the results from these experiments can be found in Table 8. Subjects who read a single specific example of a new schema could produce fairly good general descriptions of the schema (Experiment 1), they could generate a new instance of the schema as well as those who were directly taught the schema (Experiment 2), and they could answer direct questions about the schema as well as a group directly taught the schema (Experiment 3).

[Insert Table 8 about here.]

The results from the non-EBL conditions also support the account of explanation-based learning given earlier. The explanation-based learning approach predicts that when people lack sufficient knowledge to construct the explanation of a concept or when the constituents of a concept are not causally connected, they should fail to acquire a correct schema from a single example. This is what was found in these experiments.

The instance group in the non-EBL conditions did not produce general descriptions as well as those in the EBL conditions. More specifically, the instance group in the non-EBL conditions omitted

constraints more frequently than the instance group in the EBL conditions. Another major difference occurred when constraints were produced. In the EBL conditions, the constraints were almost always correct whereas in non-EBL conditions, a large percentage of constraints mentioned were incorrect.

The same contrast between the two conditions was found in the task of generating new instances of the schemata. The instance group in the non-EBL condition could not produce appropriate new instances of the schema. In addition, the instance group in the non-EBL condition omitted constraints more frequently and generated more incorrect constraints than the EBL group.

The yes/no question experiments, which eliminated some of the problems resulting from the methodology of using open-ended tasks, gave even clearer data. The subjects in the EBL condition could answer questions that required an understanding of the general abstract schema which was instantiated in the specific passage. The data showed that people can acquire a schema from a single example in knowledge-rich domains. The performance of subjects who read a single instance in domains for which they lacked knowledge was not as good as those in the EBL condition. This result highlights the role that background knowledge plays in the acquisition of a schema from a single instance.

Conclusions: Implications of the Results for Schema Acquisition Theories

As discussed earlier, traditional learning theories have assumed that multiple trials are required in acquiring a simple concept (Hayes-Roth & Hayes-Roth, 1977; Posner & Keele, 1968) or acquiring a more complex schema (Rumelhart & Norman, 1978; Schank & Abelson, 1977; Van Dijk & Kintsch, 1983). However, the present studies showed that people can learn a schema by generalizing the explanation of a single example if they can apply their background knowledge. None of the similarity-based approaches can explain the results found in the present experiments since these theories neglected the importance of prior knowledge in learning. As Murphy and Medin (1985) argued, similarity-based approaches are insufficient to explain the concept formation process. The results of the present research show that explanation-based learning is a viable psychological model of human learning in knowledge rich domains.

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Table 1

Overview of the Experiments

Experiment	Test procedure	Form of input passage	Type of schema
1	Generating a general description		Instance EBL Non-EBL
2	Producing a new instance of a schema	Instance	EBL non-EBL
		Abstract	EBL non-EBL
3	Answering yes/no questions about a general schema	Instance	EBL non-EBL
		Abstract	EBL non-EBL

Note. Instance groups read only an instantiated description of a schema whereas abstract groups read a general description of a schema. In the EBL conditions, three schemata were used: Kyeah, Forging collectables, and Con game. In the non-EBL conditions, two schemata were used: Potlatch and Korean wedding ceremony.

Table 2

List of Constraints and Variables in the Kyeah Schema

Constraints	1.	each individual cannot afford to pay for a desired purchase
	2.	the method must be fair to everybody in the group
	3.	the number of meetings must equal number of people
	4.	each person contributes the same amount of money
	5.	the money contributed should be affordable
	6.	the money received = (the money donated per person) x (the number of participants)
	7.	each person has roughly similar financial needs
	8.	the needs should be approximately equal to money received
	9.	the individuals trust each other
Variables	1.	the items to be purchased do not have to be same for the different individuals
	2.	the number of people in the group.
	3.	the time period
	4.	the people's identity
	5.	when the money is collected
	6.	the exact amount of money to be contributed
	7.	the place where the individuals purchase their items
	8.	the method of determining order

List of Constraints and Variables in Potlatch Schema

Constraints	1.	the tribes are Indians in Northern Pacific Coast of America
	2.	only a chief can hold a potlatch
	3.	the host chief wants to improve his status
	4.	the host chief should invite a guest chief who belongs to the same ancestors
	5.	the host chief and his tribe feel happy
	6.	the guest chief feels unhappy
	7.	the guest chief must take the gifts
Variables	1.	the number of people who attend the potlatch
	2.	the day
	3.	the particular valuables to be given
	4.	what is eaten during potlatch
	5.	the dancers' mask
	6.	what people wear
	7.	the way the valuables are destroyed
	8.	what other people do during the potlatch
	9.	the wealth of the guest chief

Table 3

Experiment 1: Performance of the Instance Group in Producing General Descriptions for EBL and non-EBL Passages

		Item	
Condition	Schema	Constraint	Variable
EBL	Kyeah	72.7	85.7
	Forging Collectables	82.9	98.0
	Con game	69.3	85.7
	Overall percent correct	74.9	89.3
Non-EBL	Potlatch	8.6	72.7
	Korean Wedding	22.9	78.6
	Overall percent correct	18.1	75.4

Note. The scores are the percentages of correctly identified constraints or variables.

Table 4

Experiment 2: Performance of the Instance Group and the Abstract Group in Producing a New Instance for EBL and Non-EBL Passages

		Group		
		Instance		Abstract
Condition	Schema	Constraint	Variable	Constraint
EBL	Kyeah	91.1	53.6	71.1
	Forging Collectables	68.8	80.0	81.3
	Con game	75.0	68.2	68.8
	Overall percent correct	78.8	66.3	73.6
Non-EBL	Potlatch	15.7	71.1	70.0
	Korean Wedding	9.3	76.0	56.4
	Overall percent correct	11.4	71.9	61.0

Note. The scores are the percentages of correctly identified constraints or variables.

Table 5

Experiment 3: Difference Between the Instance and the Abstract Group in Yes/no Questions for Each Schema for EBL and Non-EBL Passages

		Group	
Condition	Schema	Instance	Abstract
EBL	Kyeah	84.8	81.4
	Forging	88.1	82.4
	Con game	82.1	77.9
Overall percent correct		85.4	81.1
Non-EBL	Potlatch	54.1	76.9
	Korean Wedding	61.9	92.8
Overall percent correct		58.5	86.2

Note. The scores are the percent of correctly answered yes/no questions.

Table 6

Experiment 3: Potlatch Schema: Yes/no Questions Showing More than a 30% Difference in the Performance Between the Example Group and the Abstract Group

Questions	Group	
	Instance	Abstract
Schema Goals		
Would the guest chief be glad to receive the gifts? (No)	20.0	86.7
Was the guest chief poor? (No)	26.7	86.7
Specific Domain Knowledge		
Is this ceremony only carried out by members of the Kwakiutl tribe? (No)	46.7	93.3
Could the guest chief leave without taking the present? (No)	53.3	86.7
Unfamiliar Variables		
Could fish oil be one of the things that were given to the visitors? (Yes)	53.3	100
Could there have been dancers masked as the thunderbird gods? (Yes)	60.6	93.3
Can dried herring eggs be one of the foods to be served for the potlatch? (Yes)	60.0	93.3

Table 7

Experiment 3: Korean Wedding Ceremony Schema: Yes/no Questions Showing More than a 30% Difference in the Performance Between the Example Group and the Abstract Group

Questions	Group	
	Instance	Abstract
Specific Domain Knowledge		
Is it necessary for the ceremony to take place between strangers? (Yes)	40.0	93.3
Would it matter if a chest carrier's first child was a daughter, and his next two children were sons? (Yes)	20.0	73.3
Is it necessary that the girl's older sister be married? (Yes)	46.7	86.7
Non-causal Components		
Is it necessary that the boy bring a wooden goose for the girl? (Yes)	40.0	93.3
Is it necessary for the boy to wear blue cloth for the ceremony (Yes)	46.7	100
Unfamiliar Variables		
Is it necessary for the boy to leave his house at 8 o'clock in the morning on the day of the ceremony? (No)	46.7	100
Is it necessary for the boy and the chest carriers to pass under the oldest tree of the village where the girl lives? (No)	33.3	100
Does the woman who prepared the table have to wear blue clothes? (No)	60.0	93.3
Is it necessary that the day to send "saju tanja" to the girl's family be chosen one month after the proposal? (No)	53.3	100
Do the chest carriers have to bring two golden rings for the ceremony? (No)	20.0	100

Table 8

Overview of Results from Experiment 1, 2, and 3

Task	Item	EBL Item	Non-EBL Instance	EBL Instance	Non-EBL Abstract
General description	C	74.9	18.1	--	--
	V	89.3	75.4	--	--
New instance generation	C	78.8	11.4	73.6	61.0
	V	66.3	72.9	--	--
Yes/no questions	C	86.1	59.4	82.7	86.7
	V	84.7	55.6	79.3	85.6

Note. C = constraints; V = variables.