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Schema Acquisition From a Single Example

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This study compares Similarity-Based Learning (SBL) and Explanation-Based Learning (EBL) approaches to schema acquisition. In SBL approaches, concept formation is based on similarity across multiple examples. However, these approaches seem to be appropriate when the learner cannot apply existing knowledge and when the concepts to be learned are nonexplanatory. EBL approaches assume that a schema can be acquired from even a single example by constructing an explanation of the example using background knowledge, and generalizing the resulting explanation. However, unlike the current EBL theories, Experiment 1 showed significant EBL occurred only when the background information learned during the experiment was actively used by the Ss. Experiment 2 showed the generality of EBL mechanisms across a variety of materials and test procedures.

Two very different approaches have emerged in recent research on concept formation: similarity-based learning (SBL) and explanation-based learning (EBL). SBL theories are based on the assumption that concepts are formed by extracting similarity across multiple examples. EBL theories, which have appeared more recently, emphasize the role of prior knowledge in learning new concepts. Recent work on EBL in the area of artificial intelligence has suggested that even a single, specific example is sufficient to acquire a new concept if a machine has sufficient domain knowledge (DeJong & Mooney, 1986; Mitchell, Keller, & Kedar-Cabelli, 1986). These models have had some success in the area of machine learning, but there has been no psychological evidence showing that humans can learn concepts based on a single example using EBL approaches. The results of the present experiments support the EBL approach and show that human learners can acquire a schema from a single example in knowledge-rich domains, but not in knowledge-poor domains. They suggest that humans, learning complex information, use both SBL and EBL mechanisms.

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Similarity-Based and Explanation-Based Learning

Similarity-Based Approaches to Concept Learning

Many models of concept learning have assumed that concepts are learned through the repeated occurrence of similar instances. However, a close examination of earlier models reveals that most of the traditional models, referred to as *concept learning* models, actually include a learning mechanism that is too weak to account for many real-world examples of concept learning.

Similarity-Based Learning Models

This section briefly reviews three traditional models of simple concept learning (rule models, probabilistic models, and exemplar models; Smith & Medin, 1981) and models of more complex schema acquisition.

Rule models are based on the assumption that a concept consists of a set of defining rules and that these concepts are learned by generating hypotheses derived from initial instances and then testing the hypothesized rules (Bourne & Restle, 1959; Bower & Trabasso, 1964; Bruner, Goodnow, & Austin, 1956; Levine, 1966). In experiments designed to show rule-based learning, subjects attempt to learn the concepts by observing numerous instances of the concept. However, this may not have been the appropriate method to study learning of these types of concepts because real-world concepts with sufficient and necessary features may often be acquired by exposure to a definition, rather than by observation of multiple instances.

Probabilistic models are based on the assumption that the representation of a concept is a summary description of its exemplars (i.e., prototypes) represented, not in terms of defining features, but in terms of characteristic features (Posner & Keele, 1968; Reed, 1972; Rosch, Simpson, & Miller, 1976). Prototypes can be acquired by averaging values of exemplars on the same dimension or by combining modal values of each dimension.

Exemplar models are based on the assumption that concepts are represented in the form of a unique memory of their exemplars (Brooks, 1978; Medin & Schaffer, 1978). Much of the theoretical work in this area has been devoted to showing how prototype effects can be alternatively explained by exemplar models.

Theories of schemata (i.e., forms of knowledge representation developed to account for complex knowledge, such as knowledge of plans, spatial arrangements, or sequences of events; Brewer & Nakamura, 1984; Rumelhart & Ortony, 1977; Schank & Abelson, 1977) have typically assumed that some form of SBL accounts for schema acquisition. For example, Schank and Abelson (1977) asserted that with a series of experiences, repeated events become a part of the script, whereas nonrepeated events become changed to variables. Schank and Abelson also described how knowledge of plans and goals allows one to build explanations for specific events. However, they did not address the learning issue of generalizing such specific explanations into general purpose schemata. Rumelhart and Norman (1978) proposed that people acquire a new schema through either patterned generation, which is similar to analogy, or schema induction, which generalizes co-occurring configurations of information into a new schema. Van Dijk and Kintsch (1983) suggested that if a situation model (a form of specific representation constructed when a reader understands a text) is used frequently, it will form a context-independent script. Thus, although schema theories have attempted to make some use of preexisting knowledge, have allowed more complex forms of representation, and have used complex materials, the core learning mechanism has remained an SBL approach.

Problems With the SBL Approach

We think that the SBL approach to learning faces a number of additional difficulties: (a) Because of the relatively simple types of stimuli used in experiments to test SBL models, it has not been possible to explore different learning mechanisms for different domains. (b) The models do not take into account the role of the learner's domain knowledge. (c) The models do not make a distinction between explanatory and nonexplanatory information. (d) The learning mechanism used in these models allows spurious correlations among examples to be generalized as constraints because the generalization process is not supported by background knowledge (see Murphy & Medin, 1985, for additional discussion of the problems with SBL theories).

Simple stimuli. With the exception of experiments on schema theories, traditional concept formation experiments have almost always used simplified experimental materials. This methodological approach was adopted because it was assumed that experiments using simple materials could be better controlled than those using more realistic materials and that laws found in simplified situations could be generalized to complex situations. This methodological restriction led to the use of materials, such as dot patterns or lists of descriptions of club members, and so subjects in these experiments have had limited opportunity to apply their preexisting knowledge. *In the EBL approach, it is assumed that a special form of* learning can occur when subjects have sufficient background knowledge. Therefore, results found in simplified situations may not generalize to complex situations. In short, traditional SBL models have not considered the possible interaction between types of learning mechanisms and types of information to be learned.

Background knowledge. Many studies have pointed out the importance of background knowledge in concept formation. For example, Barsalou (1983) showed that examples sharing apparently uncorrelated properties (e.g., children, dog, stereo, and blanket) can be listed as members of a concept (e.g., "things to take from one's home during a fire") because of people's knowledge about the goal of the concept. Roth and Shoben (1983) showed that prototype effects depend on the context in which the concept is used. However, traditional SBL models have not provided a very satisfactory analysis of how an individual's learning is affected by what that individual already knows.

Explanatory versus nonexplanatory information. As a learning mechanism, SBL seems most appropriate for the nonexplanatory aspects of concepts, the features or events that occur with no underlying explanatory structure. In the domain of human actions, the conventions of society are often examples of nonexplanatory information. For example, there are different conventions in different societies about how the silverware is to be set out. Thus, one appropriate way to learn how silverware is arranged would appear to be through SBL of multiple examples. However, other aspects of human actions are imbedded in an explanatory framework. Observing multiple examples of "handing the waiter a plastic card" at the end of a meal does not seem the appropriate way to learn about this action because it requires a complex explanatory framework based on knowledge of credit and other financial aspects of technological societies. Although the nonexplanatory aspects of schemata may be learned by SBL mechanisms, we think that the explanatory aspects require different learning mechanisms.

Spurious correlations. Traditional SBL models are vulnerable to spurious correlations caused by the co-occurrence of irrelevant aspects of a concept. For example, if an SBL system is given 10 newspaper articles on kidnapping, in which all the kidnappers were wearing blue jeans, it could learn that wearing blue jeans was required for kidnapping. However, in an EBL framework, such as the one used in DeJong and Mooney (1986), learning about kidnapping would not incorporate the correlated features (wearing jeans) because it would not play a role in the explanatory structure. A learning model should be able to relate co-occurrences in the information to be learned to the goals of concepts to avoid spurious correlations.

Example. A concrete example of the role of explanation in learning can be seen in the following passage, which is taken from the materials used in Experiment 2 of the present article:

> 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.

It seems to us that in knowledge-rich domains, such as the one described in this passage, people distinguish relevant and irrelevant features of the example from a single instance and abstract the general plan. For example, people will understand that to carry out the plan described in the example, the members of the group should donate equal amounts of money and that one individual cannot receive twice as much money as the other members of the group. In addition, if a person understands the causal structure of the example, the person will understand that the members of the group do not have to buy their items at Service Merchandise and that the actual amount of the money collected need not be $50.

SBL theories do not provide a clear account of how a schema could be learned from a single, specific instance, such as the one just presented. In fact, most SBL theories would predict that no generalization will occur with a single example because these approaches do not use the explanatory structure of the example in the generalization process. Therefore, if it can be shown that people can in fact generalize and abstract a concept from a single example, then this is a fundamental problem for approaches that assume that generalization occurs only by selecting common information across multiple examples.

Explanation-Based Learning

EBL approaches emphasize the role of people's background knowledge in concept acquisition (Murphy & Medin, 1985; Wattenmaker, Nakamura, & Medin, 1987). This prior knowledge provides a learner with explanations for why examples belong to a concept. 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 (DeJong & Mooney, 1986; Mitchell et al., 1986; Winston, Binford, Katz, & Lowry, 1983; see Ellman, 1989, for reviews). Domain knowledge generally consists of rules relating form to function or schemata for known plans and actions. This knowledge is used to explain why a particular object fulfills a certain function or why a sequence of actions achieves a goal.

Although the term *EBL* has been used to cover a wide variety of methods implemented differently in various systems, there are two basic aspects of EBL systems. First, using domain knowledge, the system tries to explain why the given example is an instance of the concept under study. The explanation process is very important for learning because it separates relevant features from irrelevant ones and it provides justified generalizations that avoid spurious correlations. The second step involves a generalization process in which irrelevant features are discarded and specific values are changed to variables as long as the explanation remains valid.

An Example of an EBL System: GENESIS

GENESIS (DeJong & Mooney, 1986) is an example of an EBL system that improves its ability to understand natural language narratives by learning new plan schemata. Because the stimuli used in the current experiments are also narratives describing novel plan schemata, this particular system is 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 causally coherent interpretations (i.e., explanations) for the actions in the story.

Characters' actions can be explained in terms of later actions that they enable or in terms of ultimate goals that they achieve. GENESIS initially 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 (1983) mental model and van Dijk and Kintsch's (1983) situation model 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 way, it generalizes the specific explanation for how the goal was achieved into a general plan schema. In the current GENESIS system (Mooney, 1990), generalization is performed by a general EBL technique called EGGS (Mooney & Bennett, 1986), which determines the variables in the explanation and removes irrelevant information while maintaining the validity of the explanation. The resulting generalized schema is characterized by a set of variables that are slots that can be filled by different objects or agents in each instance and by a set of constraints that specify necessary properties of variables and necessary relationships between variables. The constraints are those properties and relationships required to maintain the causal validity of the explanation. The generalized explanation is then packaged into a schema and indexed so that it can be subsequently retrieved and used for understanding new narratives.

As an example, consider the case in which GENESIS learns a kidnapping schema from a single example. Before receiving its first kidnapping example, the system has schemata for *bargaining, capturing* and *confining, threatening,* and a number of other concepts; however, it does not have any direct knowledge about the concept of *kidnapping* for ransom. The system is given the following sample narrative:

Fred is Mary's father and is a millionaire. John approached Mary and pointed a gun at her. She was wearing blue jeans. He told her if she did not get in his car, then he would shoot her. He drove her to his hotel and locked her in his room. John called Fred and told him John was holding Mary captive. John told Fred if Fred gave him 250,000 dollars at Trenos, then John would release Mary. Fred paid him the money and John released Mary.

Using its existing knowledge, the system explains how capturing Mary allowed John to enter into a bargain with her father and thereby obtain money. This explanation is generalized and packaged into the following schema (symbols preceded by a question mark [?] are variables):

?b9 is a person. ?c4 is a location. ?r5 is a room. ?c4 is in ?r5. ?x55 is a character. ?b9 is free. ?x55 captures ?b9 and locks him/her in ?r5. ?a34 is a character. ?x55 contacts ?a34 and tells it that ?b9 is ?x55's captive. ?y5 is a valuable. ?x55 wants to have ?y5 more than it wants ?b9 to be ?x55's captive. ?a34 has a positive relationship with ?b9. ?a34 has ?y5. ?x55 and ?a34 carry out a bargain in which ?x55 releases ?b9 and ?a34 gives ?x55 ?y5 at ?l11.

This schema is then used to understand kidnapping stories with missing information that could not be understood without the schema.

EBL, such as that performed by GENESIS, is often interpreted as taking implicit knowledge (i.e., information that is already entailed by existing knowledge) and making it explicit (Dietterich, 1986; Newell, 1981). For example, given basic knowledge of human actions and goals, one might independently discover the plan of kidnapping for ransom without having to see an example. Consequently, there is disagreement about whether EBL constitutes true learning, in the sense of being inductive, rather than deductive. However, the example in EBL guides the learner to discover novel concepts that might otherwise never be acquired. In addition, concepts acquired by EBL, like concepts acquired by SBL, can be used to classify subsequent instances and make inferences about them.[1] For example, GENESIS can classify subsequent events as examples or nonexamples of kidnapping. Given the information that someone has abducted the wife of a wealthy businessman, GENESIS can use its new concept to infer that the husband will probably be asked to pay a ransom in exchange for her freedom. Therefore, EBL can also be viewed as a type of inductive concept acquisition from a single example (Flann & Dietterich, 1989).

EBL and Other Knowledge-Based Approaches

EBL must be distinguished from other knowledge-based approaches. First, schema instantiation processes should not be confused with EBL. EBL is a process that involves the learning of a new schema. Although EBL systems make use of existing schemata during learning, these schemata are not the schema to be learned, but are simply background subschemata used to construct a new schema that contains them. To ensure that we were investigating EBL in these experiments, we used only schemata that were novel to our subjects.

Second, EBL must be distinguished from general text comprehension. Text comprehension is a much broader problem than EBL because it includes vocabulary, syntax, and so on. Some text comprehension includes explanation, but for other texts (e.g., descriptions), the underlying representation is probably a spatial model, not an explanation (Brewer, 1980).

Third, the present experiments bear a complex relationship to some of Bransford and Johnson's (1972, 1973) demonstration experiments. Bransford and Johnson's "washing clothes" study showed memory improvement when an appropriate title was provided for an obtusely written text. This particular experiment is a clear example of schema instantiation (cf. Brewer, 1987, for a discussion) and so is not directly related to the current experiments. Bransford and Johnson's "Romeo" experiment showed improved text memory for subjects who had viewed a picture that provided an explanation for the text. This experiment is related to the current experiments because it nicely shows that given an appropriate knowledge framework, subjects were able to combine existing schemata into explanations for novel situations. However, Bransford and Johnson's experiment was a relatively atheoretical demonstration experiment, and unlike the present experiments, it did not address the issue of how specific explanations are generalized into new schemata.

Problems With EBL Approaches

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, successful EBL cannot occur in domains in which the understander does not have sufficient knowledge to construct an explanation. However, EBL 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, EBL systems provide no mechanism for making use of similarities across multiple examples. Lebowitz (1986) suggested integrating SBL and EBL. His UNIMEM system stores specific examples without making any generalizations and looks for commonalities among these specific instances. If it finds a commonality, it tries to construct an explanation and then constructs a generalization based on this explanation. More recent work in this area has focused on using EBL to select relevant features for an SBL system (Danyluk, 1987). However, neither of these systems have been interpreted as psychological models of learning. (See Pazzani, 1991, for a more recent attempt to integrate SBL and EBL.)

Overview of Experiments

We propose that a full account of learning requires that theories take into account the possibility that different types

[1] The construction of an EBL proof constitutes only one of several possible proofs of the concept. Therefore, a schema acquired through EBL may fail to classify an instance because it underspecifies the total concept (see Flann & Dietterich, 1989; Kedar-Cabelli, 1985; Mooney, 1991, for more details).

of knowledge require different learning mechanisms (Ahn & Brewer, 1988). The purpose of the present experiments is to examine the psychological validity and generality of EBL theories and to demonstrate the limitations of SBL and EBL theories. Some general explanation of the basic paradigm used in the current experiments is necessary.

First, we needed a measure to show that the subjects had learned the schemata used in the experiment. One clear index that an individual has acquired a schema is the ability to carry out tasks based on the structure of the schema in terms of its constraints and variables (see the previous section on GENESIS for the definition of constraints and variables and the *Method* section below for their examples). Rumelhart (1980) also pointed out the important functions of constraints and variables in schema theory. In Experiment 1, we asked subjects to make true–false judgments about the constraints and variables of the schema to be acquired. To test the generality of this approach, Experiment 2 used two additional tasks, generating new instances from a given instance and generating an abstract description of a schema from a specific instance.

Second, in all of these experiments, we paid special attention to the choice of materials, so that all schemata to be acquired would be novel to subjects. This was done to ensure that any learning taking place during the experiments was not simply due to schema instantiation.

Experiment 1

Three subexperiments in Experiment 1 tested the psychological validity of EBL and its possible limitations. In all three experiments, a schema based on a "potlatch" ceremony was used. We chose this schema for several reasons: First, few of our undergraduate subjects knew anything about the potlatch ceremony or about the general culture of the Northwestern Indians who carried out this ceremony; therefore, we could not only test the acquisition of a novel schema, but also experimentally manipulate the background knowledge required for EBL. Second, because the potlatch schema contains both causal and conventional actions, we could design the materials so that they would contain explanatory constraints, nonexplanatory constraints, and variables. Therefore, our subjects would be faced with passages containing information with very different properties. This aspect of the design allowed us to study the psychological validity of EBL (i.e., the learning of explanatory constraints and variables of schemata) as well as its possible limitations (i.e., inability to deal with nonexplanatory aspects of schemata).

The basic procedure for the experiments was as follows: Subjects first studied one or more passages depending on the group to which they were assigned. In all groups, except the abstract group, an instance passage of the potlatch ceremony was included. Then to test learning, subjects were asked to make true–false judgments on statements relating to the constraints and variables of the ceremony.

Table 1 shows what types of passages each group received. The abstract group, who received a complete abstract explanation of the potlatch schema, was included to measure an upper bound for learning the schema. The control-instance group, who received only a single instance passage of the schema, was included to measure a lower bound for learning. The groups also differed in terms of whether they received background information required for EBL. This manipulation allowed us to examine when the EBL mechanism was used. All groups in Experiments 1a and 1b received only a single instance, whereas groups in Experiment 1c received two instances. This manipulation of the number of instances allowed a test of the SBL mechanism. Finally, there was a manipulation of whether subjects were asked to describe the purpose of the ceremony before they made true–false judgments. This manipulation was designed to encourage the EBL instance group to actively use the background information they had been given to carry out EBL.

In all experiments, the subjects were undergraduate students at the University of Illinois at Urbana-Champaign participating in the experiments in partial fulfillment of a course requirement for introductory psychology. All subjects in Experiment 1 were from the same subject pool in the same semester, and they were randomly assigned to the conditions in the experiments. Experiment 1a was carried out 2 weeks before the other two experiments. This should not result in any sampling bias because selection of subjects across weeks at the University of Illinois was carried out by a computer program that randomly selected, from the subject pool, the students who were to attend each week's experiments.

Table 1
Passage Types Received by Each Group in Experiment 1

Group	Abstract passage	Background knowledge passage	Instance Passage 1	Instance Passage 2	Purpose manipulation
Experiment 1a					
Abstract	X				No
EBL-no-purpose		X	X		No
Experiment 1b					
EBL-purpose		X	X		Yes
Control-instance			X		Yes
Experiment 1c					
SBL			X	X	Yes
ESBL		X	X	X	Yes

Note. Each group received the passages marked with X. EBL = explanation-based learning; SBL = similarity-based learning; ESBL = explanation–similarity-based learning.

Experiment 1a

The purpose of Experiment 1a was to determine whether subjects could acquire a general schema from a single instance if they had sufficient background knowledge and if the schema to be learned could be causally explained. This experiment was also designed to distinguish effects due to lack of background knowledge from those due to characteristics of the information to be acquired (e.g., causal vs. conventional actions).

EBL theories predict that the instance group members, given the required background information, should perform as well on explanatory constraints and variables as the abstract group members, who were given explicit information about all aspects of the schema. However, the instance group should perform only at a chance level on nonexplanatory constraints.

Method

Subjects. Subjects in Experiment 1a were randomly assigned to one of two conditions: an abstract condition and an instance condition. There were 19 subjects in the abstract condition and 25 subjects in the instance condition.

Procedure and design. Subjects in the abstract condition received an abstract passage (see Appendix A) with all the explanations necessary to understand the potlatch schema, and then they were given nine test statements. Subjects in the instance condition first received a background information passage (Appendix B) and a test on the background information. Next, they read an instance passage of the potlatch schema (Appendix C), and finally, they were given the same test statements as the abstract group. The background knowledge passage contained all the low-level schemata needed to construct an explanation for the potlatch schema, along with some additional information irrelevant to the potlatch schema to make it more realistic. However, the background knowledge passage contained no information about the potlatch schema itself. The instance passage was a purely descriptive presentation of a particular potlatch ceremony and did not include any explanatory information, such as the purpose of the ceremony.

Pilot work had shown that our subjects did not spend much time trying to understand the background information that they needed to carry out EBL on the experimental passage. Therefore, we gave the subjects in the instance condition a test on the background information in an attempt to lead them to pay attention to this information. The subjects were instructed to study the background passage very carefully because they would be asked to make true–false judgments about the background passage without referring back to it. After they felt they understood the passage, they turned the page and made true–false judgments on the background passage. Then, they were asked to grade their own answers by referring back to the passage and then to study the items that they had missed. The subjects' responses on this comprehension test were rescored by the experimenter after the experiment. Their scores showed a relatively high level of performance (91%).

Both groups, after studying their passages, were asked to make true–false judgments for the nine statements presented in Appendix D. Items testing three types of knowledge were used for the true–false judgment task: (a) explanatory constraints (properties and relationships required for the ceremony, which can be causally explained in terms of information in the background knowledge passage), (b) nonexplanatory constraints (properties and relationships required for the ceremony, which cannot be connected to the explanation of the schema), and (c) variables (slots that can be filled by different values in each instance). There were three test statements for each of the three types of items. The order of the statements was randomized across the subjects. In addition, the subjects were asked to write down the sentence numbers for the instance and background knowledge passages on which their answers were based. This task was included to make subjects pay attention to all the sentences in the passage. They were also asked to write down justifications for their answers in detail. Finally, for each judgment, they were asked to rate their confidence on a 5-point scale. While making their judgments, they could refer back to the passages they had read.

Scoring method. The results were analyzed by item type (explanatory constraints, nonexplanatory constraints, and variables). Each subject got one point for a correct answer, and the total scores for each item type were used for the statistical tests.

For the purposes of this study, it is important to know not only what answer a subject gave, but also why the subjects chose a particular answer. Therefore, for the explanatory constraint items, further analysis was carried out that took into account the subjects' justification.

To see how the subjects' justifications for explanatory constraint items were scored, several examples follow: For the first item in Appendix D, subjects who mentioned both possible explanations (i.e., the host chief can improve his status by giving gifts to the competing chief, and the host chief should give gifts to guest chiefs who attend the ceremony as witnesses) got one point; those who mentioned one of these explanations got a half point. A point was given on the second question if the subjects stated that there should be witnesses who do not compete with the host chief. A point was given on the third question if the subject stated that the purpose of the ceremony was for the host chief to improve his status against the guest chief who had the same ancestor as the host chief.

Results

The results of this subexperiment in terms of mean percentage correct are given in Table 2, and the results in terms of mean confidence ratings are given in Table 3. The instance group is labeled as *EBL-no-purpose group* for reasons that are explained in Experiment 1b.

Analysis of percentage correct. Despite the prediction of EBL theories, the performance of the instance group given background information was not as good as that of the abstract group. For the explanatory constraint items, the performance of the instance group (61.3%, standard deviation [*SD*] = 34.26) was reliably lower than that of the abstract group (89.5%, *SD* = 20.57), $t(42) = 3.107$, $p < .005$. When a second analysis was carried out that considered the subjects' justifications for their answers to the explanatory constraint items, the instance group's percentage correct was even lower (21.3%, *SD* = 27.43).

For the nonexplanatory constraint items, the percentage correct for the instance group (50.7%, *SD* = 34.86) was much lower than that for the abstract group (100%, *SD* = 0).

Analysis of the items testing schema variables showed that there was a reliable difference between the mean percentage correct for the instance group (61.3%, *SD* = 32.9) and that for the abstract group (84.2%, *SD* = 20.4), $t(42) = 2.664$, $p < .05$.

Analysis of confidence rating. The subjects' confidence ratings for correct responses were also analyzed. For explanatory constraint items, the mean confidence rating of the instance group (3.52, *SD* = 0.82) was reliably lower than that

Table 2
Mean Percentage Correct on Each Item Type for Each Group in Experiment 1

Group	Item type				
	Explanatory constraints ECs	Correctly justified ECs	Variable	Mean of ECs and variables	Non-ECs
Experiment 1a					
Abstract	89.5	—[a]	84.2	86.8	100
EBL-no-purpose[b]	61.3	21.3	61.3	61.3	50.7
Experiment 1b					
EBL-purpose	77.8	50.0	69.4	73.6	50.0
Control-instance	72.2	0.0	50.0	61.1	75.0
Experiment 1c					
SBL	82.2	0.0	91.1	86.7	81.1
ESBL	80.5	54.0	92.0	86.3	66.7

Note. EC = explanatory constraint; EBL = explanation-based learning; SBL = similarity-based learning; ESBL = explanation-similarity-based learning.
[a] Because the abstract group directly received justifications, the number is not applicable here.
[b] The EBL-no-purpose group was originally called the *instance group* in the description of Experiment 1a.

of the abstract group (4.25, $SD = 0.85$), $t(42) = 2.876$, $p < .01$. For nonexplanatory constraint items, the mean confidence rating of the instance group (3.51, $SD = 0.89$) was also reliably lower than that of the abstract group (4.90, $SD = 0.25$), $t(42) = 6.566$, $p < .001$. For variable items, the average confidence rating of the instance group (3.39, $SD = 0.88$) was again reliably lower than that of the abstract group (4.02, $SD = 0.68$), $t(42) = 2.589$, $p < .05$.

Discussion

The results from Experiment 1a show a consistent difference in performance on schema learning for subjects who received a single instance plus background information and those who received an actual description of the underlying schema. The relatively low overall level of performance for the instance group suggests that most subjects were not carrying out EBL.

This result is consistent with the results of a number of other studies across a variety of tasks. Ross, Perkins, and Tenpenny (1990) found that people do not generalize specific features until they have to use the specific features for some other purpose. In addition, the work of Bransford, Franks, Vye, and Sherwood (1989) and that of Gick and Holyoak (1983) show that individuals often fail to spontaneously use relevant information that they have already learned.

Table 3
Mean Confidence Ratings on Each Item Type for Each Group in Experiment 1

Group	ECs	Variable	Non-ECs
Experiment 1a			
Abstract	4.25	4.02	4.90
EBL-no-purpose[a]	3.52	3.39	3.51
Experiment 1b			
EBL-purpose	3.94	3.65	3.43
Control-instance	3.26	3.04	3.17
Experiment 1c			
SBL	3.42	4.28	3.44
ESBL	4.11	4.26	3.38

Note. EC = explanatory constraint; EBL = explanation-based learning; SBL = similarity-based learning; ESBL = explanation-similarity-based learning.
[a] The EBL-no-purpose group is called the *instance group* in Experiment 1a.

Given the findings of these other studies, we hypothesized that the poor performance of the instance group might be due to the fact that EBL is a relatively effortful task and that EBL is not carried out automatically every time the appropriate information is provided. In other tasks, when subjects have not used relevant knowledge for a particular task, it has often been possible to activate that knowledge by various task manipulations. Experiment 1b was designed to look for clear evidence of EBL in a situation in which the relevant background information was actively used by the subject.

Experiment 1b

Our attempts to ensure that the subjects in Experiment 1a learned the individual elements of background knowledge may have deflected them from trying to understand the overall purpose of the potlatch ceremony and thus blocked the occurrence of EBL. In the present experiment, subjects were asked to state the purpose of the ceremony. This manipulation was designed to lead the EBL group to actively use the background information they had been given.

To see how successful the purpose manipulation was in leading the subjects to carry out EBL, this experiment included a control group that received the experimental instance passage but not the relevant background information. Comparison of the performance of the group with appropriate background knowledge (EBL-purpose group) and the group without appropriate background knowledge (control-instance group) allowed a clear examination of EBL for the same schema. The performance of both of these groups can be compared with the data from Experiment 1a for the group overtly given the underlying schema (abstract group) and for the EBL group that was not given the purpose instruction (the EBL-no-purpose group, formerly called the *instance group*).

Method

Subjects. There were 24 subjects in the EBL-purpose group and 24 subjects in the control-instance group. Subjects were randomly assigned to groups.

Design and procedure. The EBL-purpose group received the background information passage and were tested on their comprehension of the background information following the procedures used with the EBL no-purpose group in Experiment 1a. The EBL-purpose group then received the same instance passage that the EBL-no-purpose group had received. The new manipulation in Experiment 1b was that after reading the instance passage, the EBL-purpose group was asked to state the purpose of the ceremony in detail. While carrying out this task, they were allowed to refer back to both the background passage and the instance passage. They did not receive feedback on their answer.

The control-instance group received the same instance passage that the EBL-no-purpose group and the EBL-purpose group had received. They were also asked to state the purpose of the ceremony in detail. However, they were not given the background passage.

After writing down the purpose of the ceremony, both groups made true–false judgments for the nine statements listed in Appendix D. All these procedures were carried out at the subjects' own pace.

Results

The mean percentage correct for each item type for each group in Experiment 1b is given in Table 2, and the mean confidence ratings are given in Table 3.

EBL-purpose group versus control-instance group. The comparison between the EBL-purpose group and the control-instance group provides evidence for the occurrence of EBL. An individual who has learned a schema should be able to distinguish explanatory constraint information from variable information. Therefore, a good overall index of schema learning on our task that avoids base rate biases is the mean percentage correct for explanatory constraint items and variable items. The EBL-purpose group had an average score of 73.6% (SD = 18.97) on this index, whereas the control-instance group had an average score of 61.1% (SD = 18.17), a difference that was reliable, $t(46) = 2.331$, $p < .024$.

On percentage correct for explanatory constraint items, the scores for the EBL-purpose group (77.8%, SD = 28.93) were not reliably different from those for the control-instance group (72.2%, SD = 32.10), $t(47) = 1.147$, $p > .10$. However, if only answers based on correct justifications are scored, the EBL-purpose group's performance was 50%, whereas the control-instance group's scores dropped to 0% correct. On variable items, the EBL-purpose group's performance (69.4%, SD = 33.93) was reliably better than the control-instance group's (50.0%, SD = 32.60), $t(46) = 2.024$, $p < .05$.

Performance on nonexplanatory constraints is difficult to predict in this task. The EBL mechanism does not apply to nonexplanatory information so EBL makes no prediction. With multiple trials, an SBL mechanism would predict successful acquisition, but the mechanism would not apply in the case of only a single instance. The score on percentage correct for nonexplanatory information was 75.0% (SD = 29.90) for the control-instance group and 50.0% (SD = 34.06) for the EBL-purpose group. The difference was reliable, $t(46) = 2.703$, $p < .05$.

After making the true–false judgments, the subjects gave a confidence rating for each response. The confidence score on explanatory constraints for the EBL-purpose group was 3.94 (SD = 0.76), whereas that for the control-instance group was 3.26 (SD = 0.81). This difference was reliable, $t(46) = 2.990$, $p < .005$. The mean confidence rating for variable information for the EBL-purpose group (3.65, SD = 0.87) was also reliably higher than that for the control-instance group (3.04, SD = 0.97), $t(46) = 2.304$, $p < .05$. The mean confidence rating for the nonexplanatory constraints was 3.43 (SD = 0.85) for the EBL-purpose group and 3.17 (SD = 0.90) for the control-instance group; this difference was not reliable.

Overall, the data show that EBL occurred in a task that experimentally controls the background knowledge required for EBL. The EBL-purpose group performed reliably better than the control-instance group on mean percentage correct for explanatory constraints and variables, on correct justifications, and on confidence ratings for explanatory constraints and for variables.

EBL-purpose group versus abstract group. The analysis just reported shows that there was an effect of background knowledge suggesting that the EBL mechanism was being used. Additional comparisons were made between the EBL-purpose group and the abstract group to test whether the learning of the EBL-purpose group was as good as that of the group who received direct instruction about the general schema.

The EBL-purpose group's performance on explanatory constraints (77.8%) was not reliably lower than that of the abstract group (89.5%), $t(41) = 1.451$, $p = .15$. In addition, on variables, there was no reliable difference between the EBL-purpose group (69.4%) and the abstract group (84.2%), $t(41) = 1.671$, $p = .10$. However, mean percentage correct for explanatory constraints and variables of the EBL-purpose group (73.6%) was reliably lower than that of the abstract group (86.8%), $t(41) = 2.318$, $p < .05$. For nonexplanatory constraints, the predicted difference was found: The abstract group's performance (100%) was much higher than that of the EBL-purpose group (50%).

The analysis of confidence ratings for the two groups gave similar results. There was no difference between the EBL-purpose group and the abstract group on explanatory constraints (3.94 and 4.25, respectively) and variables (3.65 and 4.02, respectively). However, on nonexplanatory constraints, the abstract group (4.90) was reliably more confident than the EBL-purpose group (3.43), $t(41) = 7.262$, $p < .001$.

In Experiment 1b, subjects were asked to describe the purpose of the potlatch ceremony. This procedure was designed to increase the amount of EBL occurring during study of the potlatch passage. Overall, the purpose manipulation seemed to lead to the increased use of EBL. The differences between the abstract group and the EBL-purpose group on explanatory constraints and variables were not reliable both in terms of percentage correct and confidence ratings. In contrast, there still was a reliable difference between the two groups on nonexplanatory constraints, indicating that the effect of the purpose manipulation was due to increased use of EBL and not due to other factors, such as increased attention for the materials. However, the EBL-purpose group's performance on explanatory constraints and variables was consistently below that of the abstract group, although not reliable. Thus, it appears that direct instruction is somewhat more efficient than EBL in learning the information in this particular task.

EBL-purpose group versus EBL-no-purpose group. More direct comparisons were made to examine the effect of the purpose manipulation. Comparison of the EBL-purpose group from Experiment 1b and the EBL-no-purpose group from Experiment 1a shows that the manipulation was moderately successful. The mean percentage correct for explanatory constraints and variables for the EBL-no-purpose group (61.3%) was reliably lower than that for the EBL-purpose group (73.6%), $t(47) = 2.595$, $p < .05$. The EBL-purpose group's percentage correct on explanatory constraint items and variable items (77.8% and 69.4%, respectively) were somewhat greater than that of the EBL-no-purpose group (61.3% and 61.3%), but neither of these differences were reliable. However, the difference between the EBL-purpose (50.0%) and EBL-no-purpose groups (21.3%) on the explanatory constraint items for correct justifications was highly reliable, $t(47) = 3.293$, $p < .005$. For nonexplanatory constraints, the EBL-purpose group (50.0%) was not reliably different from the EBL-no-purpose group (50.7%; $p > .10$).

The analysis of confidence ratings found a marginally reliable difference between the two groups only on explanatory constraint items in which the mean confidence rating was 3.94 for the EBL-purpose group and 3.52 for the EBL-no-purpose group, $t(47) = 1.875$, $p = .07$. For nonexplanatory constraint items, the mean rating was 3.43 for the EBL-purpose group and 3.51 for the EBL-no-purpose group. For variable items, the mean rating was 3.65 for the EBL-purpose group and 3.39 for the EBL-no-purpose group. None of these differences were reliable.

Overall, these results show that there was an effect of the purpose manipulation on learning explanatory constraints and variables taken together. Subjects were much better at providing correct justifications for explanatory constraints when they had to describe the purpose of the schema. Although the differences for individual item types were not reliable, the EBL-purpose group's percentage correct and confidence ratings for explanatory constraints and variables were higher than those of the EBL-no-purpose group. In contrast, for nonexplanatory constraints, the direction of the difference with respect to percentage correct and confidence ratings was in the opposite direction, although unreliable. Therefore, the purpose manipulation seemed to have affected subjects' learning only on explanatory constraints and variables.

Discussion

The results of Experiment 1b on explanatory constraints and variables provide clear evidence for EBL in a task in which there was experimental control over the background knowledge used to carry out EBL. The EBL-purpose group members, who received the background information in addition to the instance passage that the control-instance group received, were better at understanding explanatory constraints and variables taken together and producing justifications for explanatory contraints. However, the results of Experiment 1a and 1b taken together also show that when subjects have to learn the relevant background knowledge immediately before applying it, the process is not automatic and schema learning by EBL is not as good as direct instruction. This conclusion can be drawn from the difference between the EBL-no-purpose group and the EBL-purpose group's performance on justified explanatory constraints and on the mean of explanatory constraints and variables.

Neither EBL nor SBL approaches make a clear prediction about the learning of nonexplanatory constraints from a single instance. The data from Experiment 1b show that the control-instance group obtained a higher percentage correct on these items than the EBL-purpose group. We think that this group, lacking any other basis for choice, may fall back on a belief (Grice, 1975) that if the author mentions something, it is important information and thus might be a constraint. This would also account for their low scores on variable items. Here their use of this strategy would lead them to postulate that mentioned values of variables (e.g., there were four guests) were constraints. This tendency did not appear among groups who were provided with domain knowledge (i.e., the EBL-purpose group and the EBL-no-purpose group). In other words, these subjects did not tend to think that an item was a constraint unless they could give an explanation for it. Therefore, the effect of unexplainable information seems to interact with its context: People tend to believe that unexplained items in an instance are constraints more easily when the instance cannot be explained at all than when some of the instance can be explained.

We think that the relatively good performance of the control-instance group on explanatory constraints (72.2%) also results from the subjects adopting the strategy that mentioned items are likely to be constraints. Therefore, the better index of performance for the control-instance group is the percentage correct on correctly justified explanatory constraints. On this index the control-instance group (0%) does not perform anywhere near as well as does the EBL-purpose group (50%).

Experiments 1a and 1b have focused on EBL and have involved schema learning from single instances. Experiment 1c uses multiple instances to study the interaction of EBL and SBL learning processes. It is quite possible that the effect of repetition of information that cannot be explained may also interact with its context: Subjects may believe that unexplained repetition indicates constraints more easily when they have no explanation for the instance at all than when they have some.

Experiment 1c

Experiment 1c was designed to examine the effect of multiple instances on SBL and EBL. There were two experimental groups in this experiment: an SBL group and an explanation–similarity-based learning (ESBL) group. The SBL group received two different instances of the potlatch ceremony. To give the SBL group the optimal information with just two instances, the values for explanatory constraint and nonexplanatory constraint items were repeated across the two examples, but the values for all variable items were changed.

This type of presentation allows the SBL mechanisms to identify all the variable items with just two instances. For example, if in the first instance of the potlatch ceremony the host chief gives away drums and in the second he gives away blankets, then the SBL learner knows that the particular items given away are not critical (i.e., they must be variables). Things are less clear-cut for the SBL group for constraints. The same values are repeated for constraints across the two examples, and thus, the SBL group must either assume that an item is a constraint on the basis of only two instances or hold that it is a possible variable even though it has been repeated in the only two instances available.

The ESBL group received not only the same two instances as the SBL group, but also the background information needed to explain the instances. Thus, the ESBL group in this experiment was able to use EBL to distinguish the explanatory constraints and to use SBL to distinguish between the variable items and the nonexplanatory constraints (see Mooney & Ourston, 1989, for an initial computer model that uses EBL to learn explanatory information and SBL to learn nonexplanatory information).

Method

Subjects. There were 30 subjects in the SBL group and 29 subjects in the ESBL group. Subjects were randomly assigned to groups.

Design and procedure. The SBL group received two instance passages, one of which was the same as the instance passage used in Experiments 1a and 1b. In the other instance passage, all constraints had the same values as the first instance passage, and all variables had values different from the first instance passage. The subjects were also told that these two passages were two instances of the same kind of ceremony. The ESBL group received the same background information that the EBL groups received in Experiments 1a and 1b and the same two instances that the SBL group received. Both groups were asked to state the purpose of the ceremony in the same way as the EBL-purpose group in Experiment 1b. After reading the passages, both groups made true–false judgments for the same statements that were used in Experiments 1a and 1b.

Results

The results from Experiment 1c are also given in Tables 2 and 3.

Control-instance group versus SBL group. The SBL group in this experiment forms a nice contrast with the control-instance group in Experiment 1b. Both groups received the same initial passage, but for the SBL group, that passage was followed up with a second instance showing optimum contrasts. On explanatory constraint items, the SBL group seemed to have some advantage over the control-instance group due to repetition of values in the constraint items (82.2%, SD = 22.70, for the SBL group and 72.2% for the control-instance group). However, the difference was only marginally reliable, $t(52) = 1.843$, $p = .07$. As expected, both groups showed little ability to justify their answers (0% correct justifications for both groups). There was little difference between the two groups for nonexplanatory information (81.1%, SD = 24.27, for the SBL group and 75.0% for the control-instance group). However, as expected, there was a strong difference between the two groups on the variable information. The SBL group was able to use SBL techniques and performed strikingly better (91.1%, SD = 17.37) than the instance group (50.0%), $t(52) = 5.369$, $p < .0001$.

Analysis of the subjects' confidence ratings for their answers also showed a similar pattern of results. Although the SBL group slightly outperformed the control-instance group in true–false judgments on explanatory constraints, the SBL group (3.42, SD = 0.84) was no more confident than the control-instance group (3.26) in their answers. On nonexplanatory constraints, no reliable difference was obtained between the SBL group (3.44, SD = 0.98) and the control-instance group (3.17). However, on variables, the SBL group (4.28, SD = 0.75) was much more confident than the control-instance group (3.04), $t(52) = 5.289$, $p < .001$.

Overall, the effect of an additional instance with contrasting values on variables appeared only in learning of variables. Repetition of instances had little effect on learning constraints. Although the SBL group consistently showed better performance on constraints than the control-instance group, the differences were not reliable. It seems that more than two instances may be necessary to convince subjects that repetition of certain values indicates that those values are constraints.

ESBL group versus EBL-purpose group. The ESBL group from this experiment can be contrasted with the EBL-purpose group of Experiment 1b. Both groups received one instance and the relevant background information for EBL, but the ESBL group also received a second instance and so could use both EBL and SBL mechanisms. There was little difference between the groups on explanatory constraints (80.5%, SD = 24.43, for the ESBL group and 77.8% for the EBL-purpose group). There was also no reliable difference in giving correct justifications for explanatory constraints (54.0% for the ESBL group and 50.0% for the EBL-purpose group). However, as predicted, there were large differences between the two groups on variables (92.0%, SD = 14.50, for the ESBL group and 69.4% for the EBL-purpose group), $t(51) = 3.237$, $p < .005$. In addition, the repeated instances improved performance on the nonexplanatory constraints (66.7%, SD = 33.33, for the ESBL group and 50.0% for the EBL group). However, the difference was only marginally reliable, $t(51) = 1.794$, $p = .08$.

Similarly, in their confidence ratings, there was little difference between the two groups on explanatory constraints (4.11, SD = 0.69, for the ESBL group and 3.94 for the EBL-purpose group) and on nonexplanatory constraints (3.38, SD = 0.93, for the ESBL group and 3.43 for the EBL-purpose group). In contrast, on variables, the ESBL group (4.26, SD = 0.73) was much more confident than the EBL-purpose group (3.65), $t(51) = 2.790$, $p < .01$.

To summarize, the largest effect of a second instance on EBL appeared in identifying variables. The increased learning of variables due to a second instance is not predicted by traditional machine-based EBL theories because they assume that the EBL mechanism will identify all variables from a single instance, so there would be no room for improvement due to a second instance. However, the present results show that human learners are more conservative in making generalizations than are machine-based EBL theories.

In addition, there also was some increase in learning of nonexplanatory constraints, although the difference was not reliable. As mentioned in the comparison between the control-instance group and the SBL group, it might be that two instances are simply not enough for the acquisition of nonexplanatory constraints.

The repetition of instances had little effect on learning explanatory constraints. This result is similar to the finding in the previous comparison between the control-instance group and the SBL group.

SBL group versus EBL-purpose group. It is also interesting to compare the SBL group who saw two instances, with the EBL-purpose group from Experiment 1b, who saw only one instance. There was little difference between the two groups on explanatory constraints (82.2% for the SBL group and 77.8% for the EBL-purpose group). However, only the EBL-purpose group could give correct justifications (0% for the SBL group vs. 50.0% for the EBL-purpose group). The SBL group's performance was reliably better on nonexplanatory constraints (81.1% for the SBL group and 50.0% for the EBL-purpose group), $t(52) = 3.917$, $p < .001$, and also better on variables (91.1% for the SBL group and 69.4% for the EBL-purpose group), $t(52) = 3.040$, $p < .005$.

Although the apparent performance on true–false judgments of the two groups for explanatory constraints was similar, the EBL-purpose group was reliably more confident (3.94) than the SBL group (3.42), $t(52) = 2.369$, $p < .05$. Apparently, the EBL-purpose group was more confident because they could give justifications for their answers. However, the SBL group was more confident in answering questions dealing with variables (4.28) than the EBL-purpose group (3.65), $t(52) = 2.845$, $p < .01$. On nonexplanatory constraints, there was little difference in the confidence ratings of the EBL-purpose group (3.43) and the SBL group (3.44).

Overall, the pattern of results shows the predicted interaction of learning mechanism and types of knowledge. For the explanatory constraints, the EBL-purpose group's performance was equivalent to the SBL group on the true–false judgments, but they showed much higher confidence about their judgments and higher scores on the index of correctly justified responses. For variables and nonexplanatory constraints, the SBL group with two optimum instances showed higher performance than the EBL-purpose group. However, an increase in the learning of variables due to a second instance was not predicted by machine-based EBL theories.

In addition, even though the SBL theories predicted the increased learning of nonexplanatory constraints due to a second instance, it is interesting to notice that the previous comparisons (i.e., the comparison between the SBL and the control-instance group and the comparison between the ESBL and the EBL-purpose group) showed no increase in learning of nonexplanatory constraints due to a second instance. On the other hand, there was a reliable difference between the SBL group and the EBL-purpose group in learning nonexplanatory constraints. The critical difference among these three comparisons is that the earlier two comparisons did not involve the manipulation of background knowledge. That is, the groups in these two comparisons either both had background knowledge or did not have it. In contrast, in the current comparison (SBL vs. EBL-purpose), the two groups differed with respect to both the number of instances and the existence of background knowledge. This effect of background knowledge in learning of nonexplanatory constraints was suggested in Experiment 1b. In discussing that experiment, we concluded that human learners assume that unexplained items in an instance are constraints more easily when none of the instance could be explained than when part of the instance could be explained. The present results suggest that the same processes are at work, so that subjects in the SBL condition are more likely to assume that nonexplanatory items are constraints than are subjects in the EBL-purpose group who have explanations for some aspects of the schema.

SBL group versus ESBL group. Finally, the two groups in Experiment 1c (the SBL and the ESBL groups) can be compared. These two groups both received the two instances, but the ESBL group also received relevant background knowledge. There was little difference between the two groups on explanatory constraints (82.2% for the SBL and 80.5% for the ESBL group) and on variables (91.1% for the SBL and 92.0% for the ESBL group). However, the ESBL group could give more correct justifications (54.0%) than the SBL group (0%). There was a marginally reliable difference on nonexplanatory constraints (81.1% for the SBL and 66.7% for the ESBL group), $t(57) = 1.908$, $p = .06$.

The analysis of confidence ratings showed that on explanatory constraints, the ESBL group (4.11) was more confident than the SBL group (3.42) probably because the ESBL group had justifications for explanatory constraints, $t(57) = 3.476$, $p < .001$. However, little difference was obtained on nonexplanatory constraints (3.38 for the ESBL group and 3.44 for the SBL group) and on variables (4.36 for the ESBL group and 4.28 for the SBL group).

It appears that adding the EBL mechanism to SBL gives the ESBL group higher performance on some tasks involving explanatory constraints, but reduces performance on nonexplanatory constraints. The reduced performance on nonexplanatory constraints is consistent with the previous discussion on the interaction between the number of instances and the existence of background knowledge: Learners appear to be more reluctant to treat repetition of values as constraints when they have explanations for some parts of instances than when they have no explanations at all.

Discussion

The overall pattern of results from Experiment 1c suggests that if learners are provided with a strongly contrasting pair of instances, then they can use SBL to select out the variables in a complex set of information. In the real world, however, it seems likely that strongly contrasting instances will not be common and so the SBL mechanism will not be as efficient as in our idealized experimental situation.

The SBL mechanism was less successful in dealing with explanatory constraints in these experiments. Subjects using this mechanism could not correctly justify explanatory constraints and were less confident in their correct answers. For this type of information, the SBL mechanism is faced with the classic problem of induction. In our experiments, the SBL groups (i.e., the SBL group and the control-instance group, lacking relevant background domain knowledge) had either one occurrence of some event (Experiment 1b) or two occurrences (Experiment 1c) and had to decide if this was a necessary aspect of the schema or merely a chance occurrence. With our materials, the SBL learners tended to adopt a strategy of guessing that the explanatory constraint events were in fact constraints, but they were not able to give explanations for why the information was a constraint for the schema, and for that reason, they were always less confident of their judgments than the EBL groups. Once the EBL groups have an explanation for something, they are not as troubled by the problem of induction from the instances because they have an explanation that tells what must be the case with future instances.

The ESBL group, provided with domain knowledge, was as good as the EBL-purpose group in answering the explanatory constraint items and in providing justifications for their answers. However, the ESBL group had an advantage over the EBL-purpose group: Because the ESBL group observed two instances with contrasting variables, they were much better and more confident in detecting variables. This result is inconsistent with the prediction from machine-based EBL theories because these theories predict that after a single instance all causally unrelated items would be changed to variables, and hence, there is no place for any effect of a second instance on variables.

Another unexpected finding appeared in learning of nonexplanatory constraints. Although the ESBL group received the same repeated information as the SBL group, they did not generalize them into constraints as much as the SBL group. As discussed in Experiment 1b, it seems that repetition interacts with the contexts in which the repetition appears. If the subjects could find explanations for some aspects of a given instance, then they tended to be more conservative in generalizing repetition into constraints than when they did not have an explanation for the repetition.

Overall, the major finding from Experiment 1 is the demonstration of EBL from single instances. This is the first experimental evidence that human beings can acquire a general schema from a single instance. However, this experiment is limited in the generality of the materials and test procedures. Experiment 2 was designed to show EBL with a wider range of materials and assessment tasks.

Experiment 2

Experiment 2 consisted of three subexperiments. The experiments used the same basic procedure as Experiment 1, but differed in the test procedures used to assess the subjects' schema knowledge. The subjects in each subexperiment received passages that were designed to allow EBL or passages that should not allow EBL. For each of these types of schemata, some subjects received passages that were instances of the schema and some received passages that were abstract descriptions of the schema. In Experiment 2a, schema acquisition was assessed with yes–no questions. In Experiment 2b, schema acquisition was assessed by having the subjects produce a new instance of the schema. In Experiment 2c, schema acquisition was assessed by having the subjects produce an abstract description of the schema. Overall, this experiment was designed to make it possible to compare schema acquisition for EBL passages with that from non-EBL passages for a variety of response measures.

Materials

EBL conditions. The ideal materials for the EBL conditions would be materials in which subjects' background knowledge could be manipulated. However, it was extremely difficult to find materials like the potlatch ceremony used in Experiment 1, so we simply used three schemata for which our undergraduate subjects would have appropriate background knowledge, but not have direct knowledge of the schema itself. Three different schemata were selected that met these criteria: (a) A cooperative buying scheme that is used in several non-Western cultures. In Korea, the system is called *Kyeah,* and in India, it is called a *chit fund* (see the example given earlier in the article). (b) A technique used by art thieves for making additional money by fencing copies of a stolen collectable (see Appendix E). (c) A confidence game known as the *phoney bank-examiner ploy* (see Appendix F; Wharton, 1967).

To ensure that these schemata were novel to the subjects, in all of the conditions in Experiment 2, subjects were asked whether they had previously heard of any of the techniques described in the passages. If they did, those data were excluded from the analysis. Furthermore, two additional studies were carried out with a separate group of subjects to show the novelty of the EBL schemata. In the first control study, subjects were shown to be much less familiar with the EBL schemata than with the types of schemata used in traditional schema experiments (Bower, Black, & Turner, 1979). The results of the second study showed that subjects could not generate the EBL plans when they were provided only with the description of the goal.[2]

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[2] In both control studies, the subjects were undergraduate students at the University of Illinois at Urbana-Champaign participating in the experiments in partial fulfillment of a course requirement in introductory psychology. In the first study, 13 subjects received five passages, including the three instance passages of the EBL schemata and two passages (a restaurant script and a visit to a doctor's office script) taken from Bower, Black, and Turner (1979). The five passages were presented to each subject in a random order. Then they were asked how familiar they were with the plan on a 7-point scale, with 1 indicating *very unfamiliar* and 7 indicating *very familiar.* The two script passages were found to be much more familiar (6.27) than the two EBL passages (2.89). All possible pairwise comparisons among the five passages showed that all the contrasts between the EBL passages and the script passages were reliable at $p < .0001$. In the second control study, 11 subjects received only a part of each passage, which described an individual (or individuals) with a specific problem (or a goal) corresponding to each schema. The subjects were asked to write a short paragraph describing how the individual or individuals could fulfill their needs. None of the suggested solutions were the same as the EBL schemata used in Experiment 2. For the Kyeah schema, the major class of responses (made by 82% of the subjects)

For each schema, we developed an instance passage and an abstract passage. For the EBL instance passages, all the variables were instantiated so that there were specific names for the characters, specific dates, and so on. The passages also contained specific instantiations of all the constraints of the schema, such as the goals of the plans and the methods used to achieve the goals. The instance passage for the Kyeah schema was given earlier in this article. Appendix G gives a list of constraints and variables for the Kyeah schema and yes–no questions corresponding to each constraint and variable. The instance passages for the other two EBL schemata are given in Appendixes E and F.

The EBL abstract passages consisted of abstract explanations of each schema. 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 *four people,* and *at a regular interval* instead of *every month,* and so on. All the constraints, including the goal of the plan and methods of achieving the goal, were given in general terms. Appendix H gives the abstract passage for the Kyeah schema.

Non-EBL conditions. The materials chosen for the non-EBL condition described schemata for which we could be fairly sure that most of our undergraduate subjects would lack appropriate background knowledge. The two schemata selected to meet this criterion were (a) a description of a traditional Korean wedding ceremony, which contained many conventional actions quite different from Western norms and (b) the potlatch ceremony used in Experiment 1 (this schema was always used without providing background knowledge in the present experiment).

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 and the motivations of the actions were not included. Appendix I gives the instance passage for the Korean wedding ceremony. Appendix J gives the list of constraints and variables for the Korean wedding ceremony and yes–no questions corresponding to each constraint and variable.

The non-EBL abstract passages consisted of abstract descriptions of the goal and procedures of the actions in the two ceremonies. However, the non-EBL schemata were written to contain a number of actions and objects that 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., in the Korean wedding, it was not possible to explain why the bridegroom is required to give a wooden goose to his future father-in-law). However, all of these noncausal actions and objects were explicitly described as constraints. Appendix K gives the abstract passage for the Korean wedding ceremony.

Test Procedures

The three subexperiments differ in the tasks used to test schema acquisition. In Experiment 2a, as in the earlier experiments, subjects received a direct test of each constraint and variable of the schema; however, in this experiment, the test was in the form of a series of yes–no questions instead of true–false judgments. Experiment 2b tested how well subjects could generate new instances of a schema. As Bartlett (1932) noted, schema processes are generative, where *generative* means a process that can deal with an infinitely large number of new instances. So this task is a different way of showing that a schema has been acquired from a single example. In Experiment 2c, subjects were asked to generate a general description of the specific instance they read. This task requires the subjects to attempt to overtly describe the underlying schema derived from an instance and so provides a third independent technique for testing for schema acquisition from single instances.

In all experiments, the subjects were undergraduate students at the University of Illinois at Urbana-Champaign participating in the experiments in partial fulfillment of a course requirement for introductory psychology. Within each EBL condition and non-EBL condition, subjects were randomly assigned to the instance or the abstract group.

Experiment 2a

Method

Design and procedure. There were four experimental conditions: EBL instance, EBL abstract, non-EBL instance, and non-EBL abstract. The EBL instance group received the three EBL instance passages, the EBL abstract group received the three EBL abstract passages, the non-EBL instance group received the two non-EBL instance passages, and the non-EBL abstract group received the two non-EBL abstract passages.

Each group was given a booklet containing the appropriate passages. Each group read the first passage in the booklet and was asked to answer the questions about each narrative with *yes* or *no.* After responding to each yes–no question, the subjects were asked to justify their responses. The subjects could refer back to the previous passage while answering the questions, and they worked at their own pace. After completing the first passage, the subjects were told to continue in the same fashion with the remaining passages. All the subjects in both groups within each condition received the schemata in the same order. After finishing the experiments, subjects were asked whether they had previously heard of any of the techniques described in the passages. None of the subjects said they had heard of similar techniques.

Materials. The materials used in this experiment consisted of the EBL instance and EBL abstract passages and the non-EBL instance and non-EBL abstract passages described earlier.

Test procedures. A set of yes–no questions was developed to test the basic constraints and a sample of variables for each schema. For each selected constraint or variable in a given schema, there was one corresponding question. For the constraint *Each person contributes the same amount of money,* the question was, "Can some people

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were either to save money in the bank and wait until they had enough money or to pool their money, decide what they would all like to have the most, and share it. The other two responses in this condition were to go to a rent-to-own place and to purchase the items on credit. For the schema relating to a technique used by art thieves and the schema relating to the "phoney bank-examiner ploy," the responses were similar to each other and very diverse across the subjects. Examples of the solutions were to become involved in organized crime (e.g., drug dealing and gambling); to kidnap someone; to rob a bank; to reconsider the decision, get a job, and work hard; to play the lottery; and so on.

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 fixed number of people required for this plan?" (correct response—no). In the EBL condition across the three schemata, there were a total of 22 questions about the constraints and 18 questions about the variables (see Ahn, 1987, for the complete set of questions). In the non-EBL condition across the two schemata, there were a total of 24 questions about the constraints and 17 questions about the variables. 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 both instance and abstract groups. The expected answer was *yes* for approximately half the questions and *no* for the other half.

Subjects. There were 30 subjects in the EBL condition and 30 subjects in the non-EBL condition. Within each condition, 15 subjects received the instance passages and 15 received the abstract passages. The subjects in the EBL condition and the non-EBL condition were run at different times, but possible sampling differences are unlikely to cause any difficulties in the interpretation of the data from this experiment because the hypothesis of interest is an interaction.

Results

Analysis of main results. The hypothesis tested in this experiment was that subjects would be able to use EBL to learn a new schema from a single instance when they could explain it, but that subjects lacking appropriate background knowledge would not be able to use EBL to learn a new schema from a single instance. Overall, the results showed strong support for these predictions.

The data were scored according to the preestablished criteria that would be expected as a result of a full understanding of the schema. As predicted, there was a reliable interaction effect between the condition and group, $F(1, 56) = 71.87$, $p < .0001$. In the EBL condition, the average overall percentage correct for the instance group was 85.4% and that for the abstract group was 81.1%. A t test showed that there was no reliable difference between the two groups, $t(28) = 1.62$, $p > .10$, indicating that the group receiving a single instance of a schema learned as much as the group given explicit instruction on the schema. In the non-EBL condition, the average percentage correct for the instance group was 58.5% and that for the abstract group was 86.2%. A t test showed a reliable difference between the two groups, $t(28) = 10.49$, $p < .001$, indicating that the subjects given an instance of a schema without appropriate background knowledge did not learn the schema as well as the group given explicit instructions about the schema.

To provide a more complete look at the data, the results were broken down into questions about variables and questions about constraints. For the questions about variables, in the EBL condition, the percentage correct for the instance group was 84.7% ($SD = 6.07$) and that for the abstract group was 79.3% ($SD = 7.39$). This difference was not reliable, $t(28) = 1.40$, $p > .10$. For questions about constraints, the mean score for the instance group was 86.1% ($SD = 7.71$) and the mean for the abstract group was 82.7% ($SD = 6.69$). This difference was also not reliable, $t(28) = 0.83$, $p > .10$.

However, in the non-EBL condition, for both variable and constraint questions, the percentage 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 $t(28) = 6.62$, $p < .0001$.

Analysis of justifications. 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 authors of the text intended to convey. Some of the yes–no questions made assumptions about the execution of the plan that could be relaxed to generate an even more general schema. Within those answers scored as incorrect, 54.3% of the instance group's justifications and 52.9% of the abstract group's justifications presented arguments that were based on a causally consistent interpretation of the schema. For example, for the question about the Kyeah schema, "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 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." Thus, with a more liberal scoring of the data that include the causally justified responses as correct, the overall number of correct responses for the EBL instance group was 93.3% and that for the EBL abstract group was 91.1%.

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 that were consistent with the schema. These low percentages in both groups are due to the opaque or the noncausal aspects of the non-EBL schemata, which made it difficult for the subjects to develop alternative explanations.

Discussion

In general, the results of Experiment 2a 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. The instance group in this experiment corresponds to the EBL-purpose group in Experiment 1b because the instance passages in this experiment contain the information about the purpose of schemata. Thus, this experiment showed the generality of the main results found in Experiment 1b; subjects given a single instance in the EBL condition can acquire the underlying schema as well as a group given an explicit abstract 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 were the group given explicit information about the schema. We think that the stronger EBL shown in Experiment 2 was due to the fact that the subjects in Experiment 2 were able to use preestablished background knowledge, whereas the background knowledge provided the subjects in Experiment 1 was not as well assimilated.

Experiment 2b

Method

The design and materials of Experiment 2b were the same as those of Experiment 2a, except that yes–no questions in Experiment 2a were not used. After reading the first passage of a booklet containing appropriate sets of passages, subjects were asked to generate another instance of the technique described in the passage. The actual instructions for the instance and the abstract groups were slightly different because of the difference 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." The rest of the procedure was the same as in Experiment 2a.

Subjects. There were 20 subjects in the EBL condition and 20 subjects in the non-EBL condition. Within each condition, 10 subjects received the instance passages and 10 received the abstract passages. The subjects in the EBL condition and the non-EBL condition were run at different times, but possible sampling differences are unlikely to cause any difficulties in the interpretation of the data from this experiment because the hypothesis of interest is an interaction.

Scoring methods. The scoring method used in this experiment was as follows: Each constraint and each variable in the schema was scored as correctly mentioned (C), incorrectly mentioned (I), or omitted (O). A variable was scored as correct if 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. In the abstract group, no score for variables was possible because there were no constants to change in their passages (e.g., number of participants, items purchased, and so on). A constraint was scored as correct if the subject's description contained a statement consistent with the preestablished 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 because it was inconsistent with the constraint, "order must be assigned randomly."

There were some complexities in scoring the data due to the subjects' use of Gricean discourse rules (Grice, 1975) when they wrote their descriptions. Subjects tended to omit items if they thought the experimenter would be able to infer the items based on what they had already written. In scoring the data, credit was given if an item was clearly presupposed. For example, in one subject's description of the Kyeah, the participants' goals were to buy a house in Switzerland, a Porsche, some land in Northern Illinois, and to travel around the world. In scoring this response, it was assumed that the stores where the items were purchased were different from the ones given in the example passage even though the subject did not explicitly mention the stores.

Depending on how the omitted constraints or variables were treated, there were several possible ways to calculate the percentage correct from the three types of response scores. First, omissions can be ignored, and the percentage correct can be calculated based on only the items explicitly mentioned. In this case, the percentage correct is the number of items correctly mentioned divided by the number of items mentioned [C/(C + I)].

Second, the omitted constraints can be considered as incorrect. Using this method, the percentage correct for constraints is the number of items correctly mentioned out of the total number of constraints [C/(C + I + O)]. The treatment of omits is important because the subjects could have omitted some constraints simply because they were lacking motivation, or because they assumed these constraints were implied in their descriptions. Treating all the omitted constraints as incorrect is a more conservative scoring method for constraints.

However, for variables, the implications of the two scoring procedures are different. It is unreasonable to count omissions as incorrect because in communicating, people usually leave out unimportant components, such as the variables (Grice, 1975). In fact, omission is one way of identifying variables and one could argue that omitted variables should be scored as correct. Thus, for variables, another scoring method is possible, in which omitted variables get credit. Adopting this scoring criterion, it is assumed that when a subject omits a variable item, it is because they believe that its particular value was not important to the overall schema. With this criterion, the percentage correct for variables is the sum of correctly mentioned items and omitted items out of the total number of variables [(C + O)/(C + I + O)]. For variables, treating all the omitted variables as identified variables is a more liberal method of scoring than the first method because there could be other reasons for omitting a particular aspect of the schema.

Thus, for both constraints and variables, there can be either a conservative or a liberal scoring method. For constraints, it is more conservative to treat omitted items as incorrect than not to include them. For variables, it is more conservative not to include them than to treat them as correct. In the present experiments, the more conservative scoring methods were used for both the constraints and variables. Thus, for constraints, *percentage correct* means C/(C + I + O), whereas for variables, *percentage correct* means C/(C + I).

Two independent judges scored the data from responses of 5 randomly sampled subjects from each group. 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

For constraints, there was a reliable interaction effect between the condition and group, $F(1, 36) = 118.3$, $MS_e = 51.91$, $p < .001$. In the EBL condition, the average percentage correct constraints for the instance group was 78.8% (SD = 9.02) and 73.6% (SD = 6.82) for the abstract group. The difference was not reliable ($p > .10$). In the non-EBL condition, the average percentage correct constraints for the instance group was only 11.4% (SD = 5.11), whereas it was 56.2% (SD = 7.71) for the abstract group. The difference was reliable, $t(18) = 15.29$, $p < .001$.

There was no difference between the two conditions in the number of changed variables. The instance group in the EBL condition changed 70.1% of the variables and the instance group in the non-EBL condition changed 72.9%. However, the instance group in the non-EBL condition omitted 61.1% of the variables, whereas the instance group in the EBL condition omitted only 20.8% of the variables. Therefore, if the more liberal scoring method were used, there would also have been a large difference here.

The results 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 with the performance of the subjects overtly given the abstract schema.

Experiment 2c

Method

As in Experiments 2a and 2b, there were two conditions (EBL and non-EBL conditions). However, unlike those experiments, there was no abstract group. Each subject was given instance passages from either of the conditions 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. To make sure the subjects understood the instructions, they were given a sample narrative and an appropriate general 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 determined 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 because it was a constraint of the skyjacking schema. In the Kyeah passage, a VCR was mentioned yet it was not a part of the Kyeah schema and so should not be incorporated in the general description.

Subjects. There were 11 subjects for the EBL condition and 10 subjects for the non-EBL condition. The subjects in the EBL condition and the non-EBL condition were run at different times.

Scoring method. The scoring method for constraints was the same as in Experiment 2b. For variables, the following method was used: 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 variable used in the instantiated passage, it was scored as incorrect. To calculate percentage correct, the conservative methods mentioned in Experiment 2b were used.

Two judges independently scored the constraints and variables for the data from 5 randomly sampled subjects from each condition. The percentage of agreement between the two judges was 87%. Because the reliability of the scoring was reasonably high, only one of the judges' scores were used for the final analysis.

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 24.4% of the possible constraints were correctly mentioned in the subjects' general descriptions. In the EBL condition, subjects identified 89.3% of the variables, whereas those in the non-EBL condition identified 75.4%.[3]

The EBL condition and the non-EBL condition differed in the rate of omission of constraints and variables. The subjects in the EBL condition omitted only 24% of the constraints and 32.9% of the variables, whereas those in the non-EBL condition omitted 74.6% of the constraints and 66.1% of the variables. Therefore, if a liberal scoring method were used, then the difference would have been much greater.

The results showed that the subjects were fairly successful at carrying out EBL from single examples as measured by their abilities to write a general description of the underlying schema. However, the performance of the subjects in the non-EBL condition was very poor. They obeyed fewer constraints and omitted more constraints and variables of the schemata. Thus, this experiment once again shows that subjects carry out EBL, but this experiment uses the ability to generate abstract descriptions as the index of schema acquisition.

General Discussion

We have proposed that there are a number of fundamental problems with SBL approaches. (a) SBL models do not take into account the role of the learner's established domain knowledge in the learning of new information. (b) The use of simple stimuli in typical SBL experiments may artificially eliminate important forms of learning (e.g., EBL). (c) SBL approaches do not distinguish explanatory information from nonexplanatory information. (d) The SBL mechanism allows spurious correlations among learned examples to be generalized as constraints. Overall, our experiments have been directed at providing evidence for EBL and at showing the limitations of SBL and EBL with the goal of working out the appropriate learning mechanisms for different domains of knowledge.

We used schemata in knowledge-rich domains as experimental materials and showed that subjects brought their preestablished knowledge into the learning task and that through EBL, they could acquire a schema even from a single instance (Experiment 2). When background knowledge was experimentally provided (Experiment 1a), subjects showed little use of EBL. However, when they were engaged in a task requiring the active use of the new background knowledge (Experiment 1b), they spontaneously carried out EBL. This finding of nonautomatic generalization by human learners was not predicted by EBL theories in the area of machine learning. Experiment 1c showed that with an optimum repetition of information, SBL could provide strong schema learning, except for the ability to provide correct justifications for explanatory constraints. The SBL group was also less confident in their answers than the groups with explanations.

Another unexpected finding from Experiment 1 is that people tend to treat unexplained items differently depending on contexts. They are more conservative in treating unexplained items as constraints when they have explanations for some parts of given instances than when they have none. This

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[3] No statistical tests were performed for this experiment because the two conditions were run at different times.

finding suggests that there are interactions between types of information and the use of EBL or SBL.

Experiment 2 demonstrated EBL with a wider range of materials and test procedures. Experiment 2b showed that human learners can carry out EBL with a task that required them to generate new instances of the acquired schema. Experiment 2c showed successful EBL with a task that required the subjects to generate abstract descriptions of the schema as the measure of schema acquisition.

To conclude, it appears that human learners do rely on an SBL mechanism if there is no knowledge to apply. They look for repetition and abstract common information and discard values of variables. However, given sufficient domain knowledge so that it is possible to construct a coherent causal structure for an example, learners do not wait for further examples, but can form a schema from even a single instance.

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Appendix A

Abstract Explanation of the Potlatch Schema Used in Experiment 1

The American Indians who lived in the Northwest part of the country frequently carried out an interesting ceremony. The general procedure of the ceremony was as follows. A host chief invited several chiefs to the ceremony. One of the guest chiefs had the same ancestor as the host chief and the rest of them had different ancestors. The purpose of the ceremony was to increase the status of the host chief and his tribe with respect to the guest chief who had the same ancestor. Both chiefs claim the same family title because they both had the same ancestor. They had to justify and validate their chiefly status, and so they compete for the status conferred by possessing the family title. The prescribed manner for doing this was to hold this kind of ceremony. The other guest chiefs who had different ancestors from the host chief were also invited to be witnesses to the ceremony and to validate the events. These guest chiefs were invited because they were in the same moiety as the host chief's wife's. Moieties were twofold divisions of a tribal group. Every individual was assigned to one of two moieties at birth, on the basis of the affiliation of his or her mother. This means that a man and his own children were inevitably in the opposite moieties. Before the ceremony, the host chief's tribe prepared for the ceremony by collecting as many masks, canoes, drums, blankets, and pieces of jewelry as they could afford. These items were highly valued in this society. The host chief wanted to give away these items because the more valuables the host chief gave away during the ceremony, the higher his status became. The host tribe also prepared food such as smoked salmon, fish oil, berries, clams, mussels, and octopus. The host chief put on his best shirt with a certain animal drawn on it. Dancers for the ceremony kept their masks and headdresses in a copper box. The guests arrived with their best shirts on. There were several animals printed on their shirts, some of which were same as the host chief's shirt, and some of which were same as those on the dress worn by the host chief's wife. The shirts were all in various colors, such as orange, blue, purple, and yellow. These animals represent the different moieties. Individuals from the same moiety wear the same kind of animal pattern. Since the guest chiefs who were invited as witnesses to the ceremony were members of the host chief's wife's moiety, the animal symbols worn by these guests were the same as hers. The women serving food wore dresses of different colors. They were all wearing sea shell necklaces and all were wearing earrings made of different kinds of materials. As the ceremony started, the host chief stood up and then dancers started entertaining the people. In the meantime, the host chief distributed the collected items (e.g., canoes, drums, blankets, and jewelry) to the guests. When the guest chief who had the same ancestor as the host chief receives the gifts, his status was reduced because in this society, an individual who received valuables from the one who had the same ancestors as his lost his status. However, the guest chiefs in a different moiety did not lose any status because they had different ancestors from the host chief. After all the guests received the gifts, the ceremony ended. The guests left through the east gate of the village.

Appendix B

Background Information for Potlatch Schema Used in Experiment 1

The following are descriptions about American Indian tribes living in the Northwest part of the country:

1. The society that these tribes belong to has two moieties. A moiety *is a societal unit,* whose members trace their relationship from a common ancestor. Every individual is assigned to one of two moieties at birth, on the basis of the affiliation of his or her mother.

2. There are hierarchical relationships among chiefs who belong to the same moiety. Therefore, some chiefs have higher status than others in the same moiety.

3. Chiefs who have the same status in the same moiety constantly compete with each other for the status but they do not compete with chiefs in the other moiety.

4. For these people, status is more important than wealth.
5. The status of a tribe is determined by the status of their chief.
6. If a tribe loses in a war, their status is reduced.
7. One's status is raised if his opponent loses face in front of other people.
8. If one marries a person in the same moiety, then the parents lose face.
9. If a man does not have a son until he becomes 44, he loses face.
10. If one receives valuable gifts from his opponent, he loses face.
11. Hosts give gifts to guests who come to a ceremony as witnesses to express gratitude.
12. Blankets, masks, canoes, and drums are considered as valuables.
13. It is unacceptable for members of this society to refuse gifts.
14. At any ceremony involving competition between two individuals from the same moiety, members of the other moiety must be present as witnesses.

Appendix C

Instance Passage of Potlatch Schema Used in Experiment 1

Guetela is a Kwkiutl chief and a descendent of Mamaleleqala. On July 13th, 1745, Chief Guetela invited four chiefs. One of the invited chiefs was Chief Qomoyue who had the same ancestor as the host chief. This chief had the same status as the host chief. The other three guests were Chief Nemqic, Chief Laokoatx, and Chief Tsamas and they were descendants of Wina. Chief Laokoatx had the same status as the host chief, Chief Tsamas had lower status than the host chief, and Chief Nemqic had higher status than the host chief. Before the ceremony, Chief Guetela and his tribe prepared for the ceremony by collecting as many blankets and canoes as they could afford. They also prepared smoked salmon and berries. As the ceremony started, Chief Guetela stood up, and faced the guests. Then dancers started entertaining the people. Smoked salmon and berries were served to all the people. In the meantime, Chief Guetela started giving away blankets and canoes to the guests. Chief Qomoyue received 603 blankets and 10 canoes; Chief Nemqic, 200 blankets and 3 canoes; Chief Tsamas, 100 blankets; and Chief Laokoatx, 230 blankets and 5 canoes. When the ceremony ended, all the guests left through the east gate of the village.

Appendix D

True–False Judgment Sentences Used in Experiment 1

Explanatory Constraints

1. In the potlatch ceremony, it is required that the host chief give away items. (True)
2. In the potlatch ceremony, it would not matter if there was no chief present with an ancestor different from the host chief's. (False)
3. In the potlatch ceremony, it is required that there be a guest chief with the same status and the same ancestor as the host chief. (True)

Nonexplanatory Constraints

4. In the potlatch ceremony, it is required that the host explanatory chief look at the guests before the ceremonial dancing starts. (True)
5. In the potlatch ceremony, it is required that the guests leave through an east gate of the village. (True)
6. In the potlatch ceremony, it would not matter if smoked salmon was not served during the ceremony. (False)

Variables

7. In the potlatch ceremony, there must be a guest chief who has lower status than the host chief. (False)
8. In the potlatch ceremony, it is required that there be four guests. (False)
9. In the potlatch ceremony, it would not matter if drums were given away. (True)

Appendix E

Instance Passage of the Art Thief Schema Used in Experiment 2

On Saturday morning the Chicago Tribune reported that "The Roof is Leaking," the latest masterpiece of the famous painter Jaque Pierre, was stolen from the Gallery of Modern Art in Chicago where it was on sale for $100,000. The Chicago police had no leads about who committed the crime. Herb Miller from Elk Grove village had stolen the painting and had a plan for obtaining even more than the appraised value of the picture, $100,000.

During the following month, Mr. Miller, a talented forger of paintings, painted 3 copies of the painting. First, he met with Mr. Thompson, president of Acme Trucking, who agreed to pay $65,000 for the stolen picture for his private collection. Mr. Miller sold Mr. Thompson one of the forgeries. Mr. Thompson never suspected it might be a forgery since he knew that "The Roof is Leaking" painting had been stolen and Mr. Miller told him details of how he had stolen it. Mr. Miller sold another forgery to Silvia Johnson, the famous movie actress who was also an unscrupulous art collector. This time he got $70,000. The final copy he sold for $60,000 to Alberto Corleone, a mafia boss. Mr. Miller knew that it was very unlikely that any of the three buyers would ever discover that they had bought a forgery since they had to keep their ownership of the painting a secret. Altogether Mr. Miller collected $195,000 and still kept the original painting for his own private collection.

(Appendixes continue on next page)

Appendix F

Instance Passage of the "Phoney Bank Examiner Ploy" Schema Used in Experiment 2

On Tuesday October 3, Mrs. Christina Isaacs went to the First National Bank and deposited $233.60 into her savings account. While she was writing out the deposit slip, Jack Thompson was apparently writing a slip next to her although he was actually copying down her name, her account number, and the amount she was depositing. Two days later, Mrs. Isaacs received a telephone call from a man who identified himself as Bill Ryan, vice president of the First National Bank. Actually it was Mr. Thompson on the phone. He said, "Mrs. Isaacs as a long-time depositor of ours, may we call on you to help us? We suspect one of our tellers of embezzling." Mrs. Isaacs was eager to help. "Correct me if I am wrong," Mr. Thompson continues. "You deposited $233.60 just two days ago. Right?" Of course he was right since he had written down this information while she was making the deposit. "I did," she said. Now Mr. Thompson said, "I don't know if you've been a victim, Mrs. Isaacs. What does your bankbook say?" Mrs. Isaacs replies, "Six thousand four hundred twelve dollars and sixty cents." The voice on the telephone said, "Humm . . . we may have a problem here. Our records don't seem to agree with yours." Now he knew the exact amount in Mrs. Isaacs' account. "What we would like you to do," he said, "is to withdraw $5,000 in cash, please, so we can trace serial numbers and fingerprints. Police detective Mathew Darwil and his partner will come to your house, give you a receipt, then take the bills for laboratory examination. And let me add, Mrs. Isaacs, in the event of an arrest and conviction, a $500 reward will be credited to your account."

Mrs. Isaacs was eager to help her bank catch an embezzler and besides she could use the $500 reward. Therefore, she did as the man instructed and withdrew $5,000 from her account. When the man who claimed to be the police detective Mathew Darwil arrived, she gave him the money. Actually the supposed detective was Mr. Thompson and it was the last Mrs. Isaacs ever saw of her $5,000.

Appendix G

List of Constraints and Variables in the Kyeah Schema Used for the Explanation-Based Learning Condition in Experiment 2

Constraints

1. The method must be fair to everybody in the group. ["In the above plan, can one member of the group get the group's money more than once?"—No]
2. The money received equals the money donated per person times the number of participants. ["In the above plan, is it necessary that the number of meetings be the same as the number of people in the group?"—Yes]
3. The money contributed should be affordable. ["Suppose 6 person group for this plan. They decided to contribute $300 every month. If one of them could afford $300 for four months, would he or she be able to join the group?"—No]
4. Each person has similar financial needs. ["Suppose there are 5 people who want to execute the above plan and two of them want to buy a house, two of them, a new car, and one of them, a microwave. Are these people a suitable group for the plan?"—No]
5. The needs should be approximately equal to money received. ["Suppose there are three people: one wants something that costs $110, another something that costs $120, and the last something that costs $135. If each contributed $50 a meeting, will this plan work?"—Yes]
6. The individuals trust each other. ["If one member of the group was known to be extremely dishonest and was assigned the first position in the random order, is it likely that the rest of the group will be willing to carry out the plan?"—No]
7. Each person cannot afford a large amount of money. ["Suppose Tom is looking for some people to execute the above plan with the goal of collecting $1,000 at one time. If Mary has $1,020 in her bank, will she be likely to join this group?"—No]
8. Each person contributes the same amount of money. ["Can some people consistently donate less than others and have the system work as described?"—No]

Variables

1. The items to be purchased do not have to be the same for the different individuals. ["Do the people have to buy different items to have this system work?"—No]
2. The number of people in the group does not matter. ["Is there any fixed number of people for this plan?"—No]
3. The time period does not matter. ["Does the time period between collecting the money have to be one month?"—No]
4. The people's identity does not matter. ["Suppose there are two people in New York and two in San Francisco. Can they execute this plan if they want to?"—Yes]
5. The amount of money to be contributed does not matter. ["Would this plan work if the total amount collected each month was $204?"—Yes]
6. The place to purchase items does not matter. ["Do the people have to buy their items at the same places?"—No]

Appendix H

Abstract Passage for Kyeah Schema Used for the Explanation-Based Learning Condition in Experiment 2

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.

Appendix I

Instance Passage for Korean Wedding Ceremony Used for the Nonexplanation-Based Learning Condition in Experiment 2

Once upon a time, in a small town, there lived a girl named Spring Moon. When she became 21, Mrs. Lee, the aunt of a boy named Brave Horse, visited Spring Moon's house. Mrs. Lee met Spring Moon's parents and told them about Brave Horse's personality, character, family, and educational background. After 30 days, the boy's parents called on a diviner and he chose March 3rd to send a "saju tanja" to Spring Moon's house. On the designated day, Spring Moon's family received a box which contained the "saju tanja" on which the hour, day, month, and year of Brave Horse's birth were written. In the box, there were red and blue blouses and two white skirts for the girl. Spring Moon's family asked Suni to tell them the boy's "saju." Spring Moon's family kept the "saju tanja." Spring Moon's parents finally came to an agreement on the ceremony day and told Brave Horse's family.

On April 5th, the designated day, Brave Horse, clad in blue clothing, left his house at 8 o'clock in the morning with Brave Horse's father and Mr. Kim who had three sons and two daughters. Brave Horse's father and Mr. Kim carried a walnut chest which contained white blankets and two golden rings. They passed under the oldest tree in the Spring Moon's village. As they arrived at the gate of Spring Moon's house, three young men of the village threw packages of ashes at the visitors. Brave Horse, after entering Spring Moon's house, presented her father with a wooden goose that he had brought from his house and then bowed to her father. The father, in turn, disappeared into a room and handed the wooden goose over to his daughter. Then Brave Horse came in the room where Spring Moon was and bowed to her. Spring Moon never looked at Brave Horse.

While all the people were going out to the hall, Spring Moon's younger brother made her laugh. In the hall, Spring Moon's older sister, dressed in blue skirts, placed two plates of rice cake, a bottle of wine, and some fruit on an oak table. Spring Moon and Brave Horse bowed to each other and exchanged three cups of wine. Spring Moon's father, standing beside a wooden pillar said, "This is the happiest day in my life."

Appendix J

List of Constraints and Variables in Korean Wedding Schema Used for the Nonexplanation-Based Learning Condition in Experiment 2

Constraints

1. The man's family proposes first. ["Can the girl's family propose first?"—No]
2. The "saju tanja" includes the hour, day, month, and year of bridegroom's birth. ["Would it matter if the saju did not include the year of boy's birth?"—Yes]
3. The bride's family asks a fortune teller about the "Saju tanja." ["Could the girl's family have asked a Buddhist priest about saju?"—No]
4. The "saju tanja" must be accepted before the wedding. ["If the girl's family returned the saju tanja, would it stop the whole process?"—Yes]
5. A fortune teller picks the day of the wedding. ["Would it matter if the boy picked the day for the ceremony?"—Yes]
6. The bridegroom's clothing is blue. ["Is it necessary for the boy to wear blue cloth for the ceremony?"—Yes]
7. The chest carriers have a male first child. ["Would it matter if a chest carrier's first child was a daughter, and his next two children were sons?"—Yes]
8. The bridegroom presents a wooden goose to his future father-in-law. ["Is it necessary that the boy bring a wooden goose to the girl's place?"—Yes]
9. The bride and the bridegroom are strangers. ["Is it possible for the ceremony to take place between strangers?"—Yes]
10. The bride and the bridegroom exchange three cups of wine. ["Is it necessary that the boy and girl exchange only three cups of wine?"—Yes]
11. The bride is not allowed to laugh or to talk. ["Would the girl's mother be happy to see her daughter laughing during the ceremony?"—No]
12. The bride is the oldest unmarried daughter of the family. ["Is the girl's older sister married?"—Yes]
13. The go-between should know about the bride and the bridegroom before matchmaking. ["Is it necessary for the go-between to know about the couple?"—Yes]
14. The diviner picks a day to send the "saju tanja." ["Is it necessary that a diviner pick a day to send saju tanja?"—Yes]

Variables

1. the relation of the go-between to the family ["In a situation of this type, could a boy's parent visit the girl's family and propose a marriage?"—Yes]
2. the day that the diviner chooses for the "saju tanja" to be sent ["Is it necessary that the day to send saju tanja to the girl's family be chosen one month after the proposal?"—No]
3. the time that the bridegroom leaves for the wedding ["Is it necessary for the boy to leave his house at 8 o'clock in the morning on the day of the ceremony?"—No]
4. the day of the wedding chosen by the diviner ["Is it necessary that this ceremony be held in April?"—No]
5. the items contained in the chest ["Do the chest carriers have to bring two golden rings for the ceremony?"—No]
6. what the chest is made of ["Is it necessary that the chest with the presents for the girl's family be made of walnut?"—No]
7. the way to get to the bride's house ["Is it necessary for the boy and the chest carriers to pass under the oldest tree of the village where the girl lives?"—No]
8. the number of young men ["Is it necessary that there be three young men in front of the girl's house waiting for the boy and the chest carriers?"—No]
9. the color of the participants' clothing other than the bride and the bridegroom ["Does the woman who prepared the table have to wear blue clothes?"—No]
10. events during the ceremony ["Must there be music during the ceremony?"—No]

(Appendixes continue on next page)

Appendix K

Abstract Passage for Korean Wedding Ceremony Schema Used for the Nonexplanation-Based Learning Condition in Experiment 2

The traditional Korean wedding procedure was as follows: The man's family must first propose marriage to the woman's family through a go-between who can be a relative, a friend, or a professional match maker. The go-between is required to know the personality, character, and educational background of the persons concerned and to report his findings to the other family. The woman to be married must be the oldest unmarried daughter of the family. After that the parents of both families interview their future daughter-in-law or son-in-law before making a final decision on the marriage. When the bride's family notifies the bridegroom's family of its acceptance of the marriage proposal, the bridegroom's family calls on a diviner and asks him to choose an auspicious day to send the "saju tanja." The saju tanja is a slip of paper on which the hour, day, month, and year of his birth are written. On the designated day the bridegroom's family sends to the bride's family a box which contains the saju tanja and a present of clothing for her blouses and skirts. The bride's family asks a diviner to foretell the degree of marital harmony between the two in reference to the bridegroom's saju tanja. The day of the wedding is chosen by a diviner and reported to the bridegroom's family. This brings to conclusion the marriage agreement of the two families. If either of the two families finds some serious defect in the other, the bride's family must return the saju tanja and the presents to the bridegroom's family. This automatically means that the engagement is broken.

On the morning of the wedding day, the bridegroom, who must be clad in blue traditional ceremonial attire, visits the bride's house. Accompanying the bridegroom are his father, uncle, a friend of his, or a married villager whose first child is a son. They must carry a chest in which some additional presents are contained. As the bridegroom arrives at the gate of the bride's house, young men of the village usually throw packages of ashes at the visitors. The first thing the bridegroom must do after he entered the bride's house is to present to her father a wooden goose that he brought with him from his house. He bows to his future father-in-law. The father, in turn, goes into another room and hands the wooden goose over to his daughter. Thereupon, the bride comes out and bows to the bridegroom. Through this process the ceremony of "presenting a wooden goose" comes to an end. The bride and the bridegroom then enter the next stage of wedding formalities. Unlike a Western wedding ceremony, there is no music and rings are not exchanged. Instead the bride and the bridegroom bow to each other and must exchange three cups of wine. During the ceremony it is forbidden for the bride to laugh, to talk, or even to raise her head. In this kind of arranged marriage, it is required that a bride and a bridegroom not know each other before the wedding ceremony.

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