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Applying General Principles to Novel Problems as a Function of Learning History: Learning from Examples vs. Studying General Statements

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Abstract

This research concerns the effect of learning history for a general principle on the ability to apply the principle to novel situations. Adult subjects learned general problem solving principles under three alternative conditions: (a) abstraction of principles from diverse examples (b) study of explicit general statements of principles and (c) practice in mapping given statements onto examples. The specific aim of this research was to explore how examples given during learning a general principle affect its application to novel problems which do not share "surface" features with the examples.

Results showed that examples did not significantly facilitate application of principles over learning only a given general statement. Moreover, subjects who abstracted principles from examples, although they had abstracted the relevant information, were significantly worse at application than subjects who learned only the general statement or who learned the given statement and examples. These subjects had particular difficulty accessing and selecting the appropriate principle for a problem.

Results suggest that the representation of specific information from examples may interfere with efficiency at matching a principle to a novel problem. Whether such interference occurs may depend on the relationship between the principle and its examples in the memory representation. This relationship may be influenced by the way examples are initially encoded.

The general concern of this research is the ability to apply an abstract concept or general principle to novel situations. It is a common intuition that specific examples are helpful in learning and being able to apply abstract principles such as general scientific principles or general problem solving strategies. Many studies on the effects of examples on the acquisition and use of a principle have focused on "surface similarities" (similarities not strictly related to the principle) between examples and new instances. For example, surface similarities with prior examples provide cues that a principle is relevant to a new situation (e.g. Ross, 1984, 1986; Lewis and Anderson, 1985). Such reliance on surface cues is a not useful if the principle is needed for novel situations "dissimilar" to learning-examples. Other research does suggest that learning-examples can aid application of a principle even when surface similarities with new instances are absent (Gick and Holyoak, 1982; Nitsch, 1977). In these studies subjects who learned a general principle from examples were better at applying the principle to novel instances than those who learned only an abstract description of the principle. However, the strength of these findings is unclear and it is also unclear what factors may allow prior examples to affect application to novel situations (Clement, 1986).

The purpose of the present research is to understand how examples given during learning a general principle affect its application to novel problems which do not share surface features with the examples. Learning histories for a general principle were varied in three ways. Subjects either had to abstract principles from specific examples, study given general descriptions of principles, or study general descriptions and examples.

The contexts in which principles were applied were also varied. Three contexts were used which differed in the extent to which the choice of a principle for a problem was specified for the problem solver. Since each context may demand different cognitive processes the effects of learning history may vary depending on context. In one context the relevant principle for a problem was fully specified for subjects and they only had to map it to the current problem. Such mapping may be described as translating the general terms of the given principle into specific problem elements that generate a solution. In the second context, the set of potentially relevant principles was specified and subjects had to select a principle from the set. Selection may involve exhaustive or terminating tests of the fit between principles in the set and the problem. In the third context no information about the relevant principle was given and subjects had to spontaneously access the principle. Such access may require spontaneously noticing a similarity between an abstract representation of the problem and the features of the relevant principle in LTM. Figure 1 summarizes the processes demanded in each context.

Figure 1. General Description of Processes Required for Application of Principles in Three Contexts.

I Mapping Only

Translating between the general terms of the principle in working memory and specific problem elements

II Selection and Mapping

Exhaustive or terminating test mappings of principles in working memory.

III Spontaneous Access and Mapping

Spontaneous similarity matching between an abstract representation of the problem and the principle held in long term memory.

It was speculated that learning histories with examples might affect application of principles for two reasons. First, similarities between the processes of deriving a principle from examples and the processes of applying it new instances may be important. In both situations subjects must translate between a specific and general representation of the principle and must explicitly distinguish between relevant and irrelevant information. Thus, even if the examples and new problems are dissimilar in surface features, the general processes used during learning are similar to those required by application. Processes used during learning may transfer to the task in which the same principle must be applied (Clement, 1986).

Second, learning with examples may affect the representation of a principle in ways that are relevant to application. For example, subjects who represent links with the examples have a concrete model of the principle which they may exploit during application to new instances (even if instances are not surface similar to the model). However, it may be crucial that subjects clearly represent the hierarchical relation between the principle itself and examples. If they inadequately differentiate their description of the principle from the examples, example-specific information may interfere with matching and mapping the principle to novel problems.

EXPERIMENT 1

Two independent groups learned general principles in one of two learning conditions: GS subjects studied given general descriptions of principles and EX subjects abstracted their own general description from diverse examples. After learning, subjects had to use the principles learned to solve novel story problems. The contexts in which they solved the problems varied in the extent to which subjects were informed that a particular principle was relevant.

Method

Subjects

Subjects were 106 undergraduate students.

Learning Materials and Task

Two principles were learned. These were highly abstract and described "survival strategies" used by organisms or organizations to solve problems. For example, according to the "convergence" principle (adapted from Duncker, 1945 and Gick and Holyoak,1983) "if a strong force cannot be sent along a single path to a target, then weak forces should be sent along many paths simultaneously."

GS subjects (n=45) studied general statements of principles (see Appendix A). Subjects paraphrased the statements from memory and then checked their paraphrase against the given statement.

EX subjects (n=40) studied two or three stories which exemplified each principle (see Appendix B). Subjects had to discover and write a general description of the "survival strategy" common in a set of examples. They also had to illustrate each main point in their description with a part of each example.

After learning, a Recall Task required subjects to describe each principle from memory.

Problem Solving Materials and Task

The Problem Solving Task included two Target problems (each soluble with a principle learned) and three Dummy problems (not soluble with either principle). The Target problems described complex "real world" problem situations (see Appendix C). (The Target problem for the convergence principle is a version of Duncker's (1945) "radiation problem").

The task consisted of three phases allowing subjects three passes at the problems. Phase 1 required spontaneous access of principles: subjects were not told that the principles learned were relevant to the problems. At phase 2 subjects had to select one of the principles for problems: subjects were told to figure out which principle applies to which problem. At phase 3 subjects only had to map a specified principle to the appropriate target problem.
Figure 2 summarizes the method for Experiment 1.

Figure 2. Outline of the Procedure for Experiment 1.

Learn Principles

GS Group	EX Group
•Study given general statement	•Discover similar principle in diverse examples
•Paraphrase from memory	•Write general description
•Correct against original	•Illustrate main points

Recall Task
Recall general descriptions

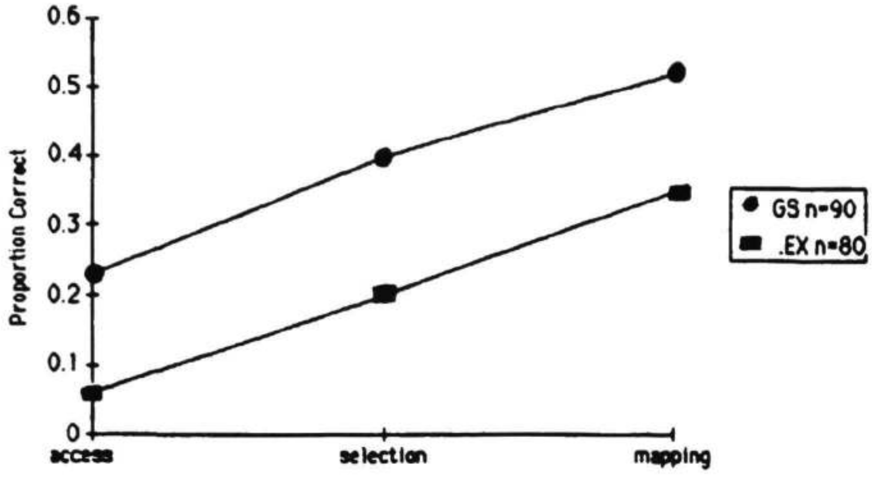
Problem Solving Task
Phase 1- Spontaneous Access and Mapping
Phase 2- Selection and Mapping
Phase 3- Mapping Only

Results and Discussion

Figure 3 shows the proportion of correct solutions to Target problems by each phase. The GS group is significantly better than the EX group at each phase (see figure note).[1] This pattern of between group differences remains when "initial learning" of the principles is taken into account, i.e. when only those subjects who accurately described principles at the recall task are considered. Among these subjects the proportion of correct solutions is higher in both groups but the difference between groups is the same.

Group differences were greatest for access and selection of principles. For mapping, the groups are equivalent for one principle (EX subjects caught up with GS subjects by the end of phase 3). For the other principle, which accounts for group differences in mapping, irrelevant information from examples appeared to lead to an incorrect instantiation of the principle by EX subjects.

Figure 3. Experiment 1. The Proportion of Correct Solutions to Target Problems in Each Group[a] by Each Phase. (Phase 1 requires spontaneous access and mapping; Phase 2 requires selection and mapping; Phase 3 only requires mapping).



[a]n=the number of responses possible in each group.

Note. Subjects who were correct at an earlier phase, and who did not change to an incorrect response, were included as correct at subsequent phases. At phase 1 statistical analyses considered the proportion of subjects who solved at least one problem, ($p=.01$, fisher exact, two tailed test). At phase 2 and 3 analyses considered the proportion of subjects solving 0, 1 or 2 problems (Chi square =7.26, df=2, $p \leq .05$ and Chi square=7.78, df=2, $p \leq .05$, at phases 2 and 3 respectively).

In sum, EX subjects were significantly worse than GS subjects at application of principles to novel problems. These results contrast with the findings of Gick and Holyoak (1983) and provide no evidence that the procedures involved in learning from examples, or the concrete model provided by examples, facilitate application of principles. Moreover, results suggest that the representation of a principle was negatively affected by learning from examples even for those EX subjects who had developed a correct description of a principle. The representation may have failed to clearly differentiate the description of the principle from the examples.

Experiment 2

In Experiment 2, a new group of subjects (PM subjects) were asked to study a given statement of a principle and then practice mapping the statement to examples. This experiment had two aims. First, PM subjects were compared to EX subjects to observe whether processing the examples under the guidance of a given statement would be important. Although PM subjects received the same examples as EX subjects, their learning task might lead to a representation in which the examples and the principle are better differentiated. PM subjects learn a statement of the principle before reading the examples and read the examples only for the purpose of finding elements which instantiate this statement. Thus their encoding of examples may be less thorough and more directed than the encoding by EX subjects. They might be less likely to encode information irrelevant to the principle and more likely to represent the hierarchical relation between the principle and the examples. The second aim of this experiment was to again assess whether examples could facilitate application; PM subjects were also compared to GS subjects from experiment 1. The practice mapping task involved procedures in which subjects had to translate between variables of the general principle and the specific elements of examples. As discussed earlier, such translation processes used during learning a principle may transfer to facilitate its later application.

Method

Subjects

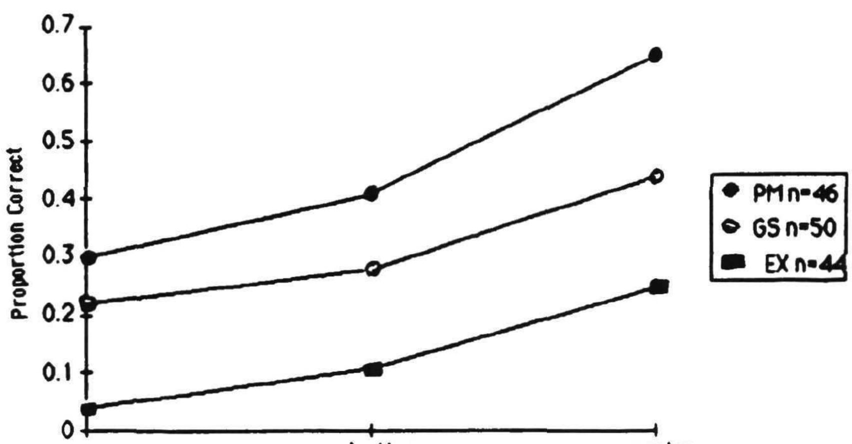
Subjects were 23 undergraduate students. These subjects were compared to a subset of GS and EX subjects in Experiment 1 chosen from the same school as PM subjects.

Design and Procedure

Subjects studied the same general statements of principles used by GS subjects in Experiment 1. Then, given the same examples used previously, they had to find the parts of each example that illustrated the ideas in the principle. (This mapping task had also been given to EX subjects after they had abstracted their general statement.)

After learning, subjects were given the recall and application task used in Experiment 1.

Figure 4. Experiment 2. The Proportion of Correct Solutions to Target Problems in Each Group[a] by Each Phase. (Phase 1 requires spontaneous access and mapping; Phase 2 requires selection and mapping; Phase 3 only requires mapping).



[a]n=the number of responses possible in each group.

Note. Subjects who were correct at an earlier phase, and who did not change to an incorrect response, were included as correct at subsequent phases. At phase 1 and 2 statistical analyses considered the proportion of subjects who solved at least one problem, ($p=.01$, fisher exact, two tailed test). At phase 3 analyses considered the proportion of subjects solving 0, 1 or 2 problems Chi square $=14.19$, $df=2$, $p \leq .001$).

Results and Discussion

Figure 4 shows the proportion correct in each group. Differences between PM and GS subjects are not significant. In contrast, differences with the EX group at each phase are significant. Again results are the same when only subjects who gave good recall descriptions of a principle are considered.

In sum, results suggest that processing the examples under the guidance of the given statement of a principle, rather than having to abstract the principle, allowed better representation and application of the principle. However, contrary to speculations, practice mapping a principle to examples did not significantly improve application over learning only the given statement.

GENERAL DISCUSSION

Subjects who abstracted a principle from examples were poor at application relative to subjects who learned only a general statement of principle even when they had abstracted the relevant information. These subjects were also poor relative to subjects who processed examples under the guidance of the general statement. One account of these findings is that EX subjects may not have adequately differentiated the description of the principle from the examples in their representation of the principle. PM subjects, whose learning task should have lead to a more differentiated representation of the specific and general information, were better at application. For EX subjects their description of the principle may have been represented as part of each example, rather than as a descriptor of a category in which the examples are some of many possible instances. The principle may not have been salient relative to other information. Or the principle may have been represented at a relatively low level of abstraction.

How would a poorly differentiated representation lead to poor application especially when spontaneous access and selection are required? One consequence may be that similarity matching between the problem and the principle is inefficient. The three application contexts may be viewed in terms of a continuum that varies in the extent to which efficient similarity matching is demanded. At one extreme is the context in which principles must be spontaneously accessed. In this context, since the principle is not already available in working memory, subjects may have to automatically notice a similarity between the problem and the principle held in long term memory. Thus, a representation of the principle which is surrounded by specific information from examples should lead to difficulty since this specific information is dissimilar to the target problem when the examples and the problem do not share surface features. (The useful similarity exists at an abstract level of representation of the problem and the principle.) In contrast, a representation of the principle which is not linked to specific examples, or in which the examples and the principle are clearly differentiated, should allow more efficient recognition of similarities between the principle and the problem.

At the other extreme of the continuum is the context in which the relevant principle is already identified and subjects only have to map it. Efficiency at similarity matching should be less of a factor here since the correct principle is already available in working memory. Subjects can work out the correspondence with the problem even if their representation of the principle is poorly differentiated from prior examples. Results suggested that with this decreased demand for efficiency a poorly differentiated representation was less of a problem. EX subjects were equivalent to GS subjects in mapping for one of the two principles. Selection errors are too complex to discuss in the present paper, but results suggest that both efficiency at similarity matching and the intrusion of irrelevant information from the examples lead to poor EX performance.

In sum, results suggest that an abstract representation of a principle, clearly differentiated from specific examples enabled the most ready application of principles to novel problems. Examples may interfere with application if the hierarchical relationship between the example-specific and general information is not clearly represented. A poorly differentiated representation may particularly affect access and selection (rather than mapping) because it may not permit efficient similarity matching. This account is consistent with recent descriptions by Gentner (1987) and Holyoak and Thagard (1986) of access and mapping processes in case-based reasoning.

Results also suggest that the way the examples are initially encoded may affect representation and application. General and particular information may be better differentiated when subjects have prior knowledge of the general principle than when they have the relevant general information only after initial processing of examples. The specific nature of the representation of the principle formed by PM and EX subjects is being explored further in current studies which are varying the similarities between target problems are prior examples.

Even when examples were processed under the guidance of a given statement of a principle application was not significantly better than when only a given statement was learned (however, a trend toward improvement with examples was found). Future research should further explore circumstances in which the processes involved in learning from examples, or the model provided by examples, can be used to facilitate application of a principle to novel instances.

Footnotes

1. In order to get a base solution rate for problems, a control group (n=21), received the Problem Solving Task but received no prior training. GS subjects but not EX subjects gave significantly more correct solutions at phase one than this base rate group.

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