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When learning new cognitive skills involving problem solving, novices are often reminded of earlier problems. The use of earlier problems is a common means of problem solving and affects the learning of the skill. This project has three aims in understanding this learning. First, the representation of the resulting generalizations is being examined. Generalizations formed from remindings are likely to be conservative, in that they may be more tied to the examples than many current theories allow. A main aim of the project is to distinguish and test different forms of this conservatism. Second, the development of problem solving expertise is examined by focusing on differences in how typical and atypical problems are solved. Third, the effects of such reminding-based learning in everyday problem solving is examined to extend the findings and test some theoretical ideas that are difficult to investigate in more formal domains.

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ANNUAL TECHNICAL REPORT: REMINDING-BASED LEARNING

OBJECTIVES

When learning a new cognitive skill, novices spend much of their time solving problems. In doing so, it is common for novices to think back to an earlier problem that the current problem reminds them of and use this earlier problem to help solve the current problem (e.g., Ross, 1984, 1987, 1989a). This use of the earlier problem not only affects performance on the current problem, but also provides the learner with additional knowledge that can be accessed and used on later problems. The aim of this research is to understand the nature of the learning that results from this use of earlier problems. Little is known about this crucial source of learning.

Such within-domain analogies occur frequently during learning. In the view presented in this work, a generalization is formed from making an analogy between problems. Rather than positing a separate generalization process that operates upon completed instances, the generalization may be a byproduct of the analogy. In using the earlier problem to help solve the current problem, comparisons must be made and some aspects generalized over. Remindings, by setting up the analogy, may determine what pairs of problems are compared and, hence, what generalizations are made. The learning comes about because, while the noticing might be based on a variety of similar aspects (including superficial c [illegible]) between the problems, the comparisons forces the generaliz[illegible]ion of many of the aspects. My earlier work (e.g., Ross & Kennedy, 1990) has shown that the use of earlier problems allows novices to begin to form generalizations across problems. Thus, this means of learning may be one way in which novices can begin to develop more expert-like knowledge structures. However, much work remains to be done to understand this learning. The research I have been conducting in the last year has three goals.

The first goal is to understand the nature of the resulting generalization, the information included in its representation. If the generalization results from the reminding, it is likely to be a conservative one, in that it will be somewhat tied to the problems from which it arises. In fact, most theories of learning assume some conservatism, but my research (a) distinguishes among different types of assumptions of conservatism, (b) relates these distinctions to current theories, and (c) tests these distinctions. Thus, this work examines the specificity of what is learned, as well as its generality.

The second goal of this research is to examine the implications of these ideas for the development of expertise. Research on expertise in mathematics and physical science domains suggests that experts have problem schemas that allow them to categorize problems, as well as associated procedures for solving problems of that type (e.g., Chi, Feltovich, & Glaser, 1981). Despite the importance of these schemas, little research examines how they are learned. A common idea is that they may develop from the comparison of problems. However, this idea leads to two questions? One, how do people know which problems to compare? Two, why are people comparing problems (i.e., what is the nature of this comparison)? The reminding-based learning view suggests that people compare problems when one makes them think back to another and they do so in order to use the earlier one to solve the current problem. In addition, this view suggests that people may develop problem schemas that are influenced by the superficial aspects, because these aspects are known to affect remindings. Thus, part of this project is concerned with the development of such problem schemas and the possibility that some schemas may critically depend upon superficial contents, even in experts.

The third goal of this project is to begin to extend this work to more everyday problem solving situations. This extension will not only allow the application and test of these ideas in an important new setting, it will also force the extension of this work to important situations that are hard to experiment with in more formal domains.

STATUS OF PROJECTS

In this section, I will provide some details of the status of the projects underway. For each goal, I will first give a brief summary of the findings and then provide further details.

1. Conservatism of learning

As described earlier, this project examines the representation of the resulting generalization. The focus here has been on asking how irrelevant aspects may affect the access and use of the generalization.

Summary. A common theme across many learning models is that generalizations are accessed solely by those features that are contained in the generalization (i.e., the features common across the instances). One experiment shows that people may first access instances to then provide access to the generalizations. That is, a manipulation that affects the access of instances improved performance even though if the instance were being used directly, performance would not have been increased (the results are below). This result, should it hold up in replications and extensions, will be difficult for many current theories to account for. In addition, another project has been examining how the representation of the generalization may depend upon the details of how the earlier problem is used.

Method. The basic paradigm for examining the effect of using an earlier problem is referred to as the cuing method. The typical experiment involves study examples, first test problems (with cues to the study examples), and second test problems. This simple case allows us to isolate the specific influences on each test and to detail the learning on a step-by-step level. More specifically, subjects are instructed in a simplified formal domain, elementary probability theory. They are given a short introduction to some probability concepts and then learn four principles (e.g., permutations). For each principle, an explanation of the principle with the appropriate formula is given. The subject then helps to solve a word problem that requires the use of the principle. This study problem is presented in a workbook format, with the subjects guided through the solution. After learning these principles (4 mins/principle), subjects are given first test problems to solve (3 mins). In many of the studies, some or all of these first test problems include a cue (e.g., "this is like the earlier golf problem"), which has been shown to result in a generalization (Ross & Kennedy, 1990). After each problem, feedback is given and subjects study the solution. A second test is then given. Of main interest is performance on the second test problem as a function of the experimental manipulation. The second test measure varies for different experiments, but for all but one of the experiments (to be noted) in this section, the measure is how able subjects are to instantiate a provided formula (i.e., they are given the appropriate formula and have to fill in the numbers correctly for the second test problem). Earlier studies have shown this use measure to be very different from the ability to determine the appropriate formula and it appears to be a function of subjects' understanding of what the variables represent. In all of these experiments, principles are rotated through conditions and several test examples are used for each principle to avoid effects due to any particular example.

1a. Can irrelevant distinctive aspects provide access to the generalization? The main study in this section provides a test of how instances and the generalizations they give rise to are related. That is, the proposal provides an analysis of a number of ways in which the instances and the generalization might be "connected". One notion of conservatism is that the generalization is still closely tied to the instances. In particular, it is possible that even some superficial aspects that occur in only one of the examples may still provide access to the generalization. This idea, if true, is problematic for many theories because they assume that the generalization includes only features that were common to the instances that gave rise to the generalization. Thus, if the superficial aspect occurred in only one instance, it could not have been in common and should not be part of the generalization. The difficulty with testing this idea is that an experimental manipulation that helps to access an instance may increase performance because the instance is used rather than because the generalization is used. (Similar to the exemplar accounts of many of the prototype effects in categorization). Thus, what is needed is a situation in which **direct** use of the instance hurts performance, while **indirect** use of the instance to access the generalization helps performance. That was the purpose of this study. (This study was the one labelled A4 in my proposal).

This experiment made use of an earlier manipulation (Ross, 1987, 1989b) in which object correspondences were shown to affect how people instantiated a formula. More specifically, if novices learn about one principle in which the variables are attached to certain objects, a later test with the same formula will often lead them to try to instantiate the formula by matching the objects. For example, if permutations were learned with the number of objects (n) being mechanics and the number of objects selected (r) being cars, at a test with the formula and a word problem involving mechanics and cars the novices would be likely to again assign mechanics to the variable n and cars to r. This assignment occurs even if the word problem has been changed to make the reversed assignment correct. Thus, these earlier studies use this manipulation of **reversed object correspondences** to show that the instantiation of the formula relies on superficial aspects. In fact, the studies in Ross (1989b) show that this superficial similarity does not have to be at the level of mechanics and cars, but rather at the level of animate and inanimate. That is, novices will also reverse correspondences if the test problem has teachers (rather than mechanics) assigned to classrooms (rather than cars).

The reason why I have gone to this level of detail is that these reversed correspondences allow a test of the issue under consideration here. In particular, assume that we have used the cuing paradigm to get generalizations. Then, we manipulate the superficial similarity of the story line to affect the likelihood of accessing a particular instance. If the instance being accessed has reversed correspondences to the test problem then using it will hurt performance. Thus, if it helps performance the instance must not have been used directly, but rather indirectly to access the generalization. The following table may help to make this concrete. The examples are written with the story content then, in parentheses a type of object correspondence in which different numbers mean unrelated correspondences and R means reversed. In both conditions, the first test problems were cued to increase the probability that a generalization was formed between the study and first test problems (as shown in Ross & Kennedy, 1990). The subjects received one of the two conditions for each principle, but had two principles in each condition.

Study example	***First Test***	***Second Test* (with formula)**
Golfers (1)	Mechanics (2)	Golfers (1-R)
Golfers (1)	Mechanics (2)	Dancers (1-R)

Consider the difference between the two conditions, which shall be called the golfers and dancers. After the first test, I assume that subjects have some information about each of the first two problems and a generalization formed by comparing the two problems (Ross & Kennedy, 1990, showed that this manipulation led to a generalization). On the second test, the golfers problem is likely to make subjects think back to the earlier study example (as has been shown a number of times in my earlier work). However, if subjects use this study example it will lead to poor second test performance because the correspondences are reversed. Thus, most theories would predict that golfers will lead to worse performance than dancers (if the study example is used) or equal performance (if only the generalization is used). However, if the study example could be used to access the generalization, then performance in golfers might be higher than in dancers.

In the experiment, the results confirmed this last prediction. A study with 24 subjects each learning 4 principles showed that performance in the golfers condition was .71 (i.e., 71% of the formulae were appropriately instantiated) compared to only .53 in the dancers condition. (Technically, the t(23) = 1.69, which is not reliable by a two-tailed test. However, this is due to one subject who showed the exact opposite effect and increased the standard deviation by 25%. I have examined the data in a number of ways and any way that reduces that subject's influence leads to a highly reliable effect, though I realize a replication will be necessary. In addition, this effect occurs for all 4 of the principles).

A parallel experiment tested the materials to show that in fact the reversed correspondences did not inadvertently help performance. In particular, this exact experiment was conducted on another 24 subjects but instead of receiving the first test problems, they participated in a filler task for the same amount of time. For the first experiment effect to be attributable to the indirect access of the generalization, it is necessary to check that the golfer problem does not lead to higher performance than the dancers problem when no generalization is likely to be formed. As expected, the golfers problem led to slightly worse performance than the dancers problem (.31 vs. .36).

A final experiment replicated the first study with the only change being a 20 minute delay between the first test and the second test. Here too the golfers problem led to higher performance, but the difference was only .40 vs. .35 and was not reliable. Although I had tested some pilot subjects with the delay, it appears that performance was hurt too much. I think that this was probably due to the filler task being more taxing than anticipated and the need to increase the study time for a delay experiment.

I believe that these studies are important for understanding the nature of the generalization and its hypothesized conservatism. I am planning further studies that will replicate the basic effect, extend it to another domain (in which the manipulations may be somewhat different), and to test additional models of conservatism as outlined in my proposal.

1b. The effect of problem use on the generalization. In addition to testing the conservatism of the generalization in the way described above, a central idea of the reminding-based view is that the generalization depends upon the earlier problem comparison. This selectivity effect has been investigated by me in the context of category learning (Ross, Perkins, & Tenpenny, 1990), because in formal domains different earlier problems will often lead to very similar generalizations. However, in this study I examine whether the details of how the problem is used (rather than which problem) affects what is learned. As will be seen, it can be viewed as a type of transfer-appropriate processing in problem solving.

The earliest studies using the cuing paradigm showed that cuing on the first test led to improved performance on the second test in three ways: better problem solving performance, higher probability of accessing the appropriate formula, and better instantiation of a provided formula (Ross & Kennedy, 1990, Exs. 1 and 2). After conducting these studies, I also became interested in problem categorization, which is thought to be a crucial element in developing expertise. Thus, I used the cuing paradigm but instead of a second test problem, subjects were given 12 problems (3 of each principle) and asked to categorize them by principle. That is, at the first test, half of the principles were cued and half were not. If cuing affects problem categorization, then higher categorization should occur for the cued principles. In one study, I gave them formulae to use as the categories for sorting and in another I gave them the principle names. The (unexpected) result was that the cuing had no effect.

My latest study investigated the following idea. There are two major differences between the cuing method and the usual way in which people think of earlier problems. First, people are reminded on their own, rather than by a cue. Although this may often make a difference about what is learned, I have some unpublished results with the cuing paradigm showing that it does not seem to have much effect in this situation. Second, usually when people are reminded they need to decide whether the reminding is appropriate. That is, they need to decide whether to use the reminding or not, since we often get reminded of earlier problems for inappropriate reasons. It seems to me that this difference may be crucial because a determination of appropriateness may include deciding whether the problems are of the same "type" so that one could be used to help solve another. Thus, such a determination might affect what is learned about problem categories.

In the study conducted so far, I have taken the same procedure and materials that led to no cuing effect and made one change. On the principles that subjects are cued, they are told there is a chance that these cues are not correct. Their task is to first decide if the cue is correct or not. They will then be given feedback on this response and given the correct cue. In fact, all the cues are correct so they are given exactly the same cues as in the earlier study, but they have to determine appropriateness before using the cued problem. The results in this case showed an effect of cuing, with the cued principles leading to .47 of the second test problems being correctly categorized compared to .30 for the not cued principles, $t(29) = 2.17$. The studies were conducted at different times and have one minor procedural difference, so I am planning to run one study in which both cuing conditions can be compared. (If the two experiments are compared, the interaction is significant, $t(68) = 2.18$).

This study extends the idea of selectivity from one of focussing on which problem is used to how it is used. In most theories of problem solving and learning, it is assumed that the problems are compared, but the different types of comparisons possible are ignored. Should these results replicate, they argue that more attention needs to be paid to the details of the use.

2. The development of problem solving expertise

As discussed earlier, reminding-based learning provides one perspective on the nature of problem schemas and their development. The work already discussed can be viewed as very early precursors to problem schemas, but no evidence has yet been presented that in fact they do lead to problem schemas. My tack in this work has been to examine the nature of pre-existing problem schemas. This work is still in early stages, so I can only present a short description that I will include in the summary.

Summary. My focus has been on the specialized schemas that often include superficial information as well. To study this, I have written a number of algebra word problems (e.g., distance, interest, mixture). Each problem has two versions: one with typical contents and one with atypical contents. The two studies conducted so far have followed up observations noted in a chapter a number of years ago (Hinsley, Hayes, & Simon, 1977). First, we have protocols of subjects solving these problems and are starting to analyze how they might differentially solve the typical and atypical (labelled B2 in the proposal). Hinsley et al. argued that the typical ones were solved by schema instantiation, while the others were solved by translating each sentence to an equation. This result is quite important, but their results were based on few observations and no quantitative data were provided. In addition, we will use these protocols to further develop ways of identifying different problem solving strategies for future studies. Second, other subjects received the same problems one clause at a time and were required after each clause to say what type of problem it is. Hinsley et al. showed people could do this quite readily. Our interest is in asking how this measure may differ for typical and atypical contents. Although I am awaiting an independent judge's tally, the preliminary results show that typical problems are categorized much earlier (a mean of 1.9 clauses vs. 3.5 for atypical). Together, these studies and the follow-up experiments will provide important information about the problem schemas and their use, particularly concerning the inclusion and use of superficial aspects.

3. Everyday problem solving

In addition to the work on probability theory and formal domains, I have been examining how remindings may be used in less formal situations. In particular, I have been examining how they may affect the simple categories that are learned. I view this work as parallel to the problem solving work, but it sometimes allows me to more cleanly investigate certain issues, especially selectivity effects. A paper that lays the basis for some of these studies will be out shortly in Cognitive Psychology and I will send some reprints along (Ross, Perkins, & Tenpenny, 1990).

Summary. The work has extended this earlier paper to show (1) that reminding-based generalizations occur in a common categorization study paradigm and (2) that remindings serve to **focus** the learner on to relevant features. I believe that this idea may help to provide one means by which categories can be learned and help relate such learning to performance issues. I am in the process of revising a chapter based on these ideas (Ross & Spalding, 1991).

3a. Reminding-based generalizations in category learning. In this study, we show that the manipulation of a feature that affects reminding (color), but which subjects know will not be included on tests, still affects what is learned about the category. As an abstract example, the letters a, b, c, d, e, f, g and h stand for features (e.g., a might be "likes gardening"). Subjects then learned about people from two categories. The structure for each category was as follows (the other category had the same structure but e, f, g, h occurred twice and a, b, c, d occurred once):

Person 1 has features	a	b	e
Person 2 has features	a	c	f
" 3 " "	d	b	g
" 4 " "	d	c	h

The experimental manipulation was that for half the subjects Persons 1 and 2 were presented in red and Persons 3 and 4 in green. For the other half of the subjects Persons 1 and 3 were in red and Persons 2 and 4 in green. Subjects knew that the tests would not include color. They were shown each of the 8 people (4 for the other category) once per block in an anticipation learning paradigm until a learning criterion was met. A number of different tests were then given. The results were quite clear: those features correlated with color (e.g., a and d for the first half of subjects) were viewed as more representative and important to the category. For instance, if a correlated feature from one category was presented with a non-correlated feature from the other category, .74 of the categorizations favored the correlated feature. Note that in all cases, the four critical features (a, b, c, d) occurred equally often with the category (and half as often with the other category). Thus, it appears that the reminding features of color were used to in some way "organize" the category and notice common features within each part. Further experiments will extend this finding and test alternative explanations.

3b. Remindings serve to focus the learner. One hypothesis that has not been tested in the formal domains is that remindings help novices to focus on relevant features. That is, one difficulty novices have is that they are not sure what information is relevant. If a novice is reminded of an appropriate earlier problem, however, the commonalities are much more likely to be relevant (compared to the non-common aspects) and thus the novice may tend to focus more on these common aspects. The category paradigm presents a nice opportunity to examine this hypothesis. In this study, 40 subjects were presented three times with 9 members of a single category and told to try to learn about the category for a future test. As in the above experiment, color was correlated with some feature. In this study, it was correlated with the value of the first dimension or the second dimension. Each dimension had three values (e.g., hobby - painting, photography, weaving) and the three colors were presented with the same value each time. In addition, half the subjects learned instances with only two dimensions, while half learned instances with four dimensions (the values for the third and fourth dimensions were uncorrelated with other dimensions). The idea was that the two dimension case was simple enough to learn completely, so any focussing effect of reminding was unnecessary. However, the four-dimension case was much more complicated and remindings would help learners to focus. For the test, subjects ranked how important the three values of dimension 1 and the three values of dimension 2 were (i.e., the 6 values were ranked 1 to 6). The results confirmed these predictions. In the two-dimension condition, those values correlated with color led to only a .1 rank difference (out of a possible 3). In the four-dimension condition, the difference was 1.2, with 18 of 20 subjects showing the effect. The interaction with the two-dimension condition was reliable as well.

These studies add not only to the idea of reminding-based learning, but also to how categories might be learned. Future studies will extend these findings with an emphasis (as in the proposal) on the effects of knowledge.

General Summary

I have presented a brief summary of the results from the projects addressing the three objectives. Although I do not think that any of the projects are yet ready for publication, I believe that each of them are potentially publishable, with the uncertainty due to the need for more experiments. The next experiments to conduct for each project are being planned (or have been) and I hope to complete them during the next year.

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