Procedures are Only Skin Deep: The Effects of Surface Content and Surface Appearance on the Transfer of Prior Knowledge in Complex Device Operation

Tenaha O'Reilly (toreilly@ualberta.ca)
Department of Psychology, University of Alberta
Edmonton, Alberta, Canada T6G 2E9

Peter Dixon (peter.dixon@ualberta.ca)
Department of Psychology, University of Alberta
Edmonton, Alberta, Canada T6G 2E9

Abstract

In this research, we investigated the factors that mediate the use of prior knowledge in learning new procedures. Participants learned to operate two different versions of four tasks on a hypothetical device interface. At a conceptual level, all devices were operated in the same way. However, in some conditions, the appearance of the two versions was manipulated by changing the graphical appearance of the interface. A second manipulation concerned the physical layout: The position of the device controls, graphics, and gauges was either the same or different from one version to the next. Providing the same appearance and providing the same physical layout both increased the amount of transfer. These effects were additive, suggesting that the factors contribute independently to learning. Our interpretation is that appearance affects the use of semantic constraint, while layout affects the use of structural analogy.

Introduction

The aim of the present investigation was to discover the effect of prior knowledge on the acquisition of novel procedures. More specifically, we were interested in determining how superficial task features are used to activate relevant prior knowledge. Ross (1987, 1989) demonstrated that in solving probability problems, superficial similarity in content has a large effect on performance. Performance was relatively poor, for example, when a study problem involved salesmen choosing mechanics to work on a car and the test problem involved mechanics choosing which salesman's car to work on. Learners were affected by these superficial correspondences even though, as far as the solution of the problem was concerned, these characteristics were entirely arbitrary. Furthermore, when participants were explicitly cued to the corresponding aspects of previously learned problems (e.g., "This is like the earlier problem with the golfers getting prizes"), they show increased transfer compared to those who were not so cued (Ross & Kennedy, 1990). Taken together, the results suggest that domain novices are often affected by the irrelevant (superficial) aspects of the problem when they should be more concerned by the deeper (structural) components.

In a similar vein, we investigated the effect of superficial features in the procedural domain of device operation. We propose that the use prior procedural knowledge is mediated by two processes: semantic constraint and structural analogy. Constraint operates by restricting the nature of the actions that are deemed to be appropriate at each step of the procedure. For instance, familiarity with other electronic devices might dictate that an initial step should be some form of power-up or reset operation. Structural analogy fosters transfer by mapping steps from a familiar procedure onto the steps required in a novel procedure. For example, a novel telephone might be operated by mapping the previously learned steps needed to make a phone call onto the corresponding steps needed for the new phone. In previous research, we have found that both processes contribute to transfer when a person is explicitly cued to use their prior knowledge (O'Reilly and Dixon,1999). However, superficial similarity (such as a label applied to the subprocedure) seemed to affect only the semantic constraint process, not the use of structural analogy.

The goal of the present research was to further investigate the nature of the superficial similarity cues that might be involved in the use of prior knowledge in general and semantic constraint specifically. To address this issue, we asked participants to learn eight different tasks on different device consoles, with the last four tasks constituting different versions of the first four. The different versions of a task could differ in physical appearance (with different logos and graphical feedback) or layout (with different control positions and groupings). Despite the different superficial appearances between the versions, the operating procedures for both could be interpreted as having the same semantic context. For example, if the steps for one version included pressing buttons labeled STORE, TRANSFER, INNER, the steps for the second version would have the semantically similar labels MEMORY, MOVE, and CENTRAL. By manipulating both the appearance and layout, we hoped to identify some of the factors that contribute to superficial similarity.

Method

Participants

The sample consisted of 24 introductory psychology students from the University of Alberta who were given extra credit for their participation.

Materials

Seventeen hypothetical device consoles were simulated on a computer screen. The device consoles consisted of a distinctive dialog box with labeled buttons; subjects operated the devices by using a computer mouse to click on the buttons in a particular order. All device consoles contained a set of ten buttons. Six of the buttons were used to carry out the procedure, and four served as distracters to make the task more difficult. One device was used as practice; the remaining 16 consisted of 4 different versions of 4 test procedures on a hypothetical weather monitoring device. These procedures were Start-up, Sensor Activation, Data Location, and System Cleaning. For each procedure, there were two different appearances consisting a distinctive font, manufacturer name and logo, and style of meter (used for feedback). In addition, for each device, appearance was crossed with two alternative spatial arrangements of the buttons, meter, and graphics. Participants were provided with a two-page instruction booklet which described the nature of a device console, the number of consoles they were required to learn, and the consequences of making both correct and incorrect button sequences. The instructions also explained that each console was operated by pressing 6 buttons in sequence. Finally, it was mentioned that the first four consoles were different and unrelated to one another while the second set of four consoles *could* be either similar or dissimilar to the previous four device consoles.

Design and Procedure

Participants were 24 University of Alberta undergraduates. Participants learned 9 tasks to a criterion of two correct trials in a row. First, participants learned a task using the practice device console. This was followed by four training and then four transfer tasks. The corresponding training and transfer devices always used the same procedure but the appearance could be either the same or different, and the physical layout could be either the same or different from training. Corresponding button labels between the two versions of a device were roughly synonymous. All four combinations of same or different appearance and layout were used for each participant. The order of these four transfer conditions as well as the particular devices and versions used in condition were counterbalanced across subjects.

Before beginning each task, all participants were asked to carefully read the two page instruction booklet. After reading the instructional materials participants were encouraged to operate the device. When a participant made an error, the task was aborted by the computer, feedback was given regarding the correct alternative that should have been pressed, and the participant was required to start the task from the beginning. When a participant made a correct button press, the reading of the feedback meter increased to a value corresponding to the total number of correct steps completed.

Results and Discussion

For each participant, four relative error rates were obtained by dividing the total number of errors on a training task by the total number of errors on the corresponding transfer task. Due to the variability of this measure, the resulting error rate was transformed logarithmically. That is, transfer was defined as:

$$T = \ln \frac{N_2}{N_1} = \ln N_2 - \ln N_1 \qquad (1)$$

where N_1 is the number of errors on the training task, and N_2 is the number of errors on the transfer task. Figure 1 shows the amount of transfer as a function of version and layout; higher scores indicate more transfer. The results can be summarized as follows: Providing the same physical layout increased the amount of transfer from training, and providing the same appearance aided the transfer process but to a somewhat larger extent. These effects were almost perfectly additive.

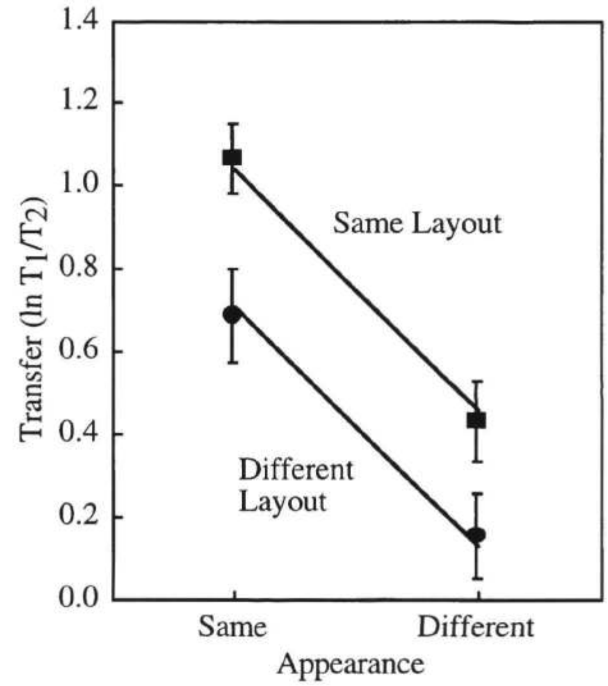

Figure 1. Transfer as a function of condition. Points on the graph represent the mean of the log relative errors in each condition, while the lines represent the predictions generated by a purely additive model. Error bars indicate standard errors of the mean.

This pattern of results can be readily interpreted in terms of the processes of semantic constraint and structural analogy. For simplicity, we assume that each step is learned independently in an all-or-none manner. Under this assumption, the total number of errors on a task is given by:

$$N = \frac{1-r}{s} \tag{2}$$

where r is the probability of guessing the step correctly and s is the probability of learning the step on a given trial. This learning model is essentially a variation of the all-or-none (one element model) described by Bower (1961). Further, we assume that semantic constraint limits the number of possible buttons that might be considered on each step and hence is reflected in the parameter r. In contrast, the successful formation of a structural analogy would mean faster learning of the steps of the procedure, and hence would be reflected in the parameter s. Combining Equations 1 and 2 allows one to rewrite transfer as the sum of two components:

$$\begin{aligned} T &= \ln N_1 - \ln N_2 \\ &= [\ln(1-r_1) - \ln s_1] - [\ln(1-r_2) - \ln s_2] \\ &= [\ln(1-r_1) - \ln(1-r_2)] + [\ln s_2 - \ln s_1] \\ &= R + S \end{aligned} \tag{3}$$

where R reflects the increment from training to transfer in the guessing rate (based on semantic constraint) and S reflects the change in how quickly individual steps are learned (based on structural analogy processes). In other words, factors having selective effects on semantic constraint and structural analogy should be additive.

Based on this analysis, our interpretation of the present results is that superficial appearance affects semantic constraint, while layout affects the formation of an analogy. For example, participants might use the graphical logo or the manufacturer's name as a cue for retrieving information about a previously learned procedure; when these are the same from training to transfer, participants may be able to recall the semantic content of the steps that are needed for the new task. In contrast, the results for the layout factor suggest that the formation of an analogy with an earlier task is based on the physical location of the controls. Consequently, when a new layout is used, participants have difficulty mapping the current steps onto those learned previously. The major implication of the present pattern of results is that these processes of constraint and analogy can go on separately and independently, at least in tasks like the present one.

A similar patter of results was obtained by O'Reilly and Dixon (1999) using a different set of tasks and different manipulations. In that study, participants learned two longer tasks that were divided into labeled subprocedures. Performance on the second (transfer) task was examined as a function of whether or not the labels were the same as those used in the first (training) task and whether or not the steps in each subprocedure were in the same order. Analogous to the present results, labels and step order had additive effects on transfer. The interpretation is that presence of identical labels fostered the use of semantic constraint, while having the steps in the same order made the process of mapping the steps from the current task to the earlier one easier. The fact that these effects were additive suggests, as here, that constraint and analogy are separate and independent processes.

Our approach to understanding the present results is based on the assumption that transfer in situations such as the present one is primarily mediated by relatively specific memory representations. An alternative orientation is to explain the operation of complex devices is to assume that participants form a mental model of the internal workings of a device (e.g., Kieras & Bovair, 1984) and use this information to infer task goals and procedures (e.g., Kamouri & Kamouri, 1986). For instance, Kieras and Bovair provided one group of participants a detailed mental model on the internal workings of a hypothetical device and another group of participants with no such model. Participants who were provided with the mental model were more likely to take shortcuts in the procedures and execute the procedures faster than the no-model group. The authors concluded that the provision of a mental model facilitated the participant's ability to draw inferences about the internal working of the device and its operating sequence.

Results such as these may reflect the same mechanisms as the effects on semantic constraint observed in the present study. For example, it might be hypothesized that the effect of superficial appearance here arises because the graphics remind users of a conceptual model they derived during the corresponding training task. Such a conceptual model in turn may allow users to make reasonably accurate guesses about which button to press when. However, the effect of layout suggests that there is another mechanism contributing to transfer that is independent of this form of conceptual knowledge. In particular, we argue that this effect is produced because subjects can map the sequence of physical button locations from the training task to the transfer task.

As alluded to earlier, the additive nature of the present results suggest that both appearance and layout contribute independently to procedural transfer. Previous investigations suggested that the *content* of superficial features affects prior knowledge use (Ross, 1987, 1989). The present findings build on this research research by showing that participants use the superficial *appearance* of a device interface to access previous experience. Further, the spatial layout of the interface may make applying analogical processes either easy or difficult. This poses special concerns for interface designers: Not only are the physical features (i.e, graphics, meters, and the appearance of controls) important in designing user-friendly interfaces, but the spatial organization of the steps in the procedure matters as well. However, our interpretation is that these variables have their effects for different reasons: Appearance is important for using semantic constraint, but spatial layout is important for mapping steps across procedures in an effective way.

Acknowledgments

This research was supported by the Natural Science and Engineering Research Council of Canada through a graduate fellowship to the first author and a research grant to the second.

References

Bower, G.H. (1961). Application of a model to paired-associate learning. *Psychometrika, 26*, 255-280.

Kamouri, A. L., Kamouri, J., & Smith, K, (1986). Training by exploration: facilitating the transfer of procedural knowledge through analogical reasoning. *International Journal of Man and Machine Studies, 24*, 171-192.

Kieras, D. E., & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science, 8*, 255-273.

O'Reilly, T., Dixon, P. (1999). The transfer of prior knowledge in complex procedural domains: Evidence for routine availability (Unpublished manuscript).

Ross, B. (1984). Remindings and their effect on learning a cognitive skill. *Cognitive Psychology, 16*, 371-416.

Ross, B. (1987). This like that: The use of earlier problems and the separation of similarity effects. *Journal of Experimental Psychology: Learning, Memory and Cognition,14*, 629-639.

Ross, B. (1989). Distinguishing types of superficial similarities: Different effects on the access and use of earlier problems *Journal of Experimental Psychology: Learning, Memory and Cognition, 15*, 456-468.

Ross, B. & Kennedy, P.T. (1990). Generalizing from the use of earlier examples in problem solving *Journal of Experimental Psychology: Learning, Memory and Cognition, 16*, 42-55.