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The Effect of Practice on Strategy Change

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Abstract

Some effort has been made to examine why people often do not adopt efficient strategies, however little attempt has been made to determine the conditions that support strategy generation. This study examines how practice may lead to efficient strategy generation, through perceptual noticing and the elaboration of a device representation. Forty-three participants were required to complete drawing tasks in MS PowerPoint, for which there are a number of possible strategies that share the same component operators, and yet vary in efficiency. Merely by practicing a component of a less efficient strategy, a more efficient strategy was generated earlier on in the experiment. Further, the efficiency of the strategy used at test was correlated with device knowledge. It is proposed that through practice a user's device representation becomes elaborated, and this in turn leads to strategy generation. The possibility of a perceptual noticing mechanism for problem solving was also investigated, however providing strong perceptual groupings did not aid strategy generation.

Introduction

A reliable finding in experimental psychology is that practice on a task leads to faster and less erroneous performance of that task. In the 1920s Snoddy (1926, as cited in Anderson, 1995) graphed learning data and demonstrated that a power function characterises the rate of improvement in the performance of a task. This means that with practice the speed at which people complete a task increases with diminishing returns (Newell and Rosenbloom, 1981).

A growing body of evidence suggests that power law learning occurs within strategy, and not with regards to the task as a whole (Rickard, 1997; Delaney, Reder, Staszewski and Ritter, 1998). Compton and Logan (1991) suggest that improvement in the performance speed of a task is often due to the adoption of more refined and effective strategies.

However, there appears to be evidence that people do not adopt efficient strategies as rapidly as might be expected. Early explanations for this failure centred around the Einstellung effect, where prior experience results in a reluctance to investigate alternative procedures for a novel task (Luchins, 1942). Inefficient use of a device was also investigated using the ACT theory of skill acquisition (Anderson, 1982) where procedures that hinder completion of a task are discarded upon detection, however procedures that are sufficient and yet inefficient are less easily identified and so are maintained. In considering the problem of inefficient device use, Carroll and Rosson (1987) suggest that people are trapped by a production paradox, meaning that users are so focused on completing tasks, that they are unlikely to take time out to learn about a device. Paradoxically, if time were spent learning about the device, performance might be improved in the long term.

More recent evidence suggests that even people who are very skilled at a set of tasks are also not likely to operate as efficiently as might be expected (Nilsen et al., 1993; Nilsen, Jong, Olson and Polson, 1992). For example Young and MacLean (1988) found users do not always choose the faster method when presented with several different routines. Bhavnani and John (1997) observed that even after several years of experience and formal training in a particular CAD package, many users had not adopted efficient strategies. Further, the use of inefficient strategies impacted upon completion times and caused an increase in low level error. Bhavnani, John and Flemming (1999) highlight the difficulty of moving from "sufficient use to a more efficient use of computer applications" (p.183). The reason for this inefficiency, they suggest, is not related to the standard of interface design or experience with the package, but to strategic knowledge. Once participants received both traditional command based training ('learning to do') and strategic knowledge training ('learning to see' or recognize opportunities for efficient strategies to be used), it was found that most tasks were performed using efficient strategies (Bhavnani et al., 1999; Bhavnani, in press). However, the relative success of those who received strategic knowledge training should not be too surprising, as during the extensive training stages participants were explicitly taught each strategy. The tests therefore are more of an ability to recall and apply efficient strategies to novel situations, rather than strategy generation per se.

Some would argue that the use of strategies, that on the surface appear inefficient, could actually be rational.

Potential costs associated with strategy generation, such as time spent exploring the device and searching through problem space, could outweigh the benefits that a possible new strategy may deliver. It may therefore be rational to maintain sufficient, yet inefficient procedures. For example with regards to choice between strategies, Young and MacLean (1988) found that where the effort of using a strategy is perceived to be high, people are prepared to 'trade off' the possible benefits of using that strategy. Users choose to continue with a method that is easier to implement, yet results in a slower task completion time.

Early attempts at investigating strategy change by Anzai and Simon (1979) found that participants spontaneously advanced through several strategies when solving the Tower of Hanoi task. Their explanations for efficiency gaining strategy changes included both mechanisms that perform modifications on existing procedures to make them more efficient (such as the identification and removal of redundant steps), and also a mechanism for perceptual noticing. In the Tower of Hanoi, this perceptual noticing mechanism identifies that the problem can be restructured in terms of pyramids.

Recent attempts to model strategy generation and change include Shrager and Siegler's (1998) SCADS simulation. Mechanisms for strategy generation and change proposed by Crowley, Shrager and Siegler (1997) were used to simulate children's use of addition strategies. Shrager and Siegler's (1998) model represents a significant step forward in understanding. However, due to the focus of the model, the reasons that people fail to apply the hypothesised mechanisms for strategy generation are not considered.

The study reported provides evidence for the conditions that support strategy generation. While some effort has been spent examining the failure of people to use optimal strategies, little evidence exists about how and when people generate new strategies. Crowley et al. (1997) suggest that during practice people make a method more efficient by identifying and eliminating redundant sub-procedures. However it is possible that practice results in efficient performance through other mechanisms such as perceptual noticing of task related features and elaboration of the user's device representation. Perceptual noticing may involve both noticing the structure of the task and the structure of objects to which operators are applied. Known operators could, as a result, be applied more efficiently. Practice may also allow elaboration of the device model through incidental learning, and this in turn may permit a more comprehensive, high quality search for efficient procedures.

The task used in the experiment is a computer-based drawing task, similar to that used by Bhavnani et al. (1999), and was selected for its ecological validity. The task provides a rich domain for studying strategy change as the basic fence, copy and paste operations can be embedded within a range of relatively sophisticated strategies for complex drawings. For example, people asked to draw a series of repeated items may use the recursive multiple-item-copy (MIC) strategy. This is where a single item is copied, then the resulting pair, and then all of the objects are copied again. The number of objects increases exponentially.

Also, following the proposal of a perceptual noticing mechanism by Anzai and Simon (1979), the task was either presented with a strong pattern that contained groupings useful to the development of the efficient strategy, or with no groupings. A mechanism for perceptual noticing should lead the user to be more likely to generate a multiple item copy strategy where groupings allude to the strategy.

The study is designed to determine whether merely practicing known procedures makes the generation of efficient strategies more likely. The importance of a mental representation of both the device and task, and their development through practice, will be examined. It is hypothesised that practice on the components of a non-optimal strategy can establish the prerequisites, through elaboration of the device representation, for the generation of a new strategy.

Method

Participants
Forty-three regular computer users, first and second year psychology undergraduates ranging in age from 18 to 32, took part in the experiment for course credit. All participants were given 2 hours of course credits to take part in the study, no matter how long they took (the average time taken was approximately 1 1/2 hours), in order to encourage efficient completion of the tasks.

Design
The study involved two between subjects manipulations. Although all of the participants knew the component procedures necessary for the efficient strategy to be used, the manner in which they were practiced varied. Practice trials involved different objects, same objects or same objects with space between them (see Table 1). The second manipulation was the pattern of the test item. In order to use MIC it was hypothesized that a participant must make certain perceptual groupings. Where there was a patterned test item, the objects were arranged so that the groupings necessary to use MIC were already present (Figure 1).

Procedure and Materials
The participants completed an informed consent form and a brief questionnaire to determine prior experience

with Microsoft PowerPoint, as well as other software packages with drawing functions. The tuition phase was then completed, which ensured that the participants mastered basic drawing skills (such as drawing, moving and altering shapes, and selection of single items by fencing), and were also made aware of the existence of some functions, including copy and paste. The participants were informed that they should only use functions identified in the tutorial stage. These included fencing, copying and pasting, but, for example, excluded duplication and grouping.

After the tuition phase the participants completed an open-ended questionnaire designed to assess knowledge about the device. Ten questions relevant to the key concepts particular to the MIC strategy were included. Five questions related to fencing multiple objects with space between them and five related to the manipulation of multiple objects. The participants were then given the same pre-test version of the test stimuli and asked to complete the drawing in as few moves as possible. The pre-test item consisted of eight equally spaced two-item objects (P- in Figure 1). If a participant completed the pre-test using any form of MIC (see Table 2) they were excluded from the analysis.

The main series of items were then presented. Each participant carried out four practice trials (see Table 1), filled in the device representation questionnaire (same as before), and then completed a saturation trial. The saturation trial involved drawing one shape, fencing it and using copy and paste to create another identical shape. This was designed to make sure all participants had fence, copy and paste functions readily available to them in memory. Half of the participants were then presented with a patterned test trial (P+) and half were presented with a non-patterned test trial (P-).
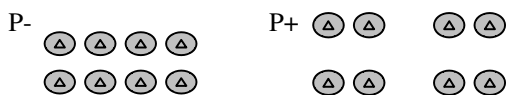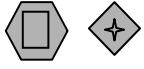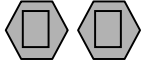

Figure 1: Non-patterned and patterned test trials

Four practice trials, the device representation questionnaire, saturation trial and test stage were repeated four times. All participants received exactly the same instructions and drew the same stimuli, except for the type of practice trials and the pattern of the test trials. Therefore each group had the same opportunity (in five test trials) to use the efficient strategy.

Table 1 shows examples of the practice tasks. The different practice trials allowed differential experience with the operators fence, copy and paste. All the participants used the operators in the saturation trial, yet in the practice trials they were used in different ways.

Table 1: Practice trials

Practice group	Explanation
1: Different objects	Participants drew each shape one-by-one, as it was not possible to use fence, copy and paste.
2: Same objects	The participants drew the first two shapes that constitute the first object, and used fence, copy and paste to complete the task.
3: Same objects with space	Participants drew the two shapes on the left and used fence, copy and paste to complete the drawing.

If participants had not used the exponential MIC strategy during the first five test trials they were given five more opportunities to do so. They were instructed to complete the task as efficiently as they could, minimising the number of steps taken to complete the task.

Microsoft PowerPoint '97 was used to carry out the drawing tasks, these were all video recorded.

Coding of Strategies

There are at least seven strategies that can be used to complete the task with the functions made available to the participants (those identified in the tuition phase). Multiple Items Copy (MIC) is the most efficient manner of performing the task. This strategy involves fencing (as depicted in Figure 2), where all objects within the fence become selected, and the manipulation of more than one object at a time.
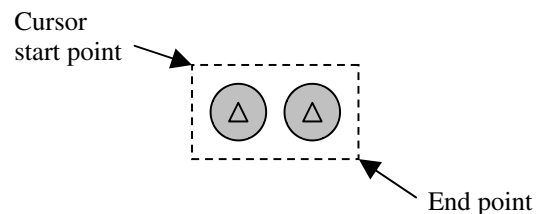

Figure 2: Fencing, by using the mouse to click and drag from the start point and releasing at the end point

There are some key concepts that must be understood before each strategy (see Table 2) can be used. Each practice group differs in their experience of these concepts. Firstly it must be appreciated that copy and paste can be used on a single item once it is selected, this being a central concept for the use of Element Copy strategy. All practice groups experience this through the saturation trial. Secondly it must be understood (to use DAC and MIC) that more than one item may be

selected by using a fence, and that copy and paste can be performed on all selected items at once. Only the two 'same objects' practice groups (2 & 3) experienced this. Finally, to use MIC it must be appreciated that items with space between them can be selected by using a fence, and that all selected items can then be manipulated together. Only the 'same objects with space' practice group experienced this.

Table 2: Possible strategies for completion of the task, result of GOMS analysis and points awarded

Strategy name, points for use and GOMS analysis result	Classification requirements and Example
Element-by-element (EBE) 1 *153s*	Each two item picture is drawn element by element (a square would be drawn and then a triangle, process repeated 7 times).
Division (D) 2 *133s*	All of the first shape are drawn and then all of the other shape (all the squares drawn, then all triangles).
Element copy (EC) 3 *101s*	Copy and paste are used on single shapes (one square would be drawn, copied and pasted 7 times, and then the same for the triangle).
Detail Aggregate Copy (DAC) 4 *64s*	All the details are completed in the first object, then it is fenced, copied and pasted seven times (a house would be drawn and then fenced, copied and pasted 7 times).
Multiple Items Copy (MIC$_1$) 5 *53s*	As with DAC, but once the first 4 copies are in place, they are all fenced, copied and pasted to make 8.
Multiple Items Copy (MIC$_2$) 6 *50s*	As with DAC, but once the 2nd copy is in place, both are fenced, copied and pasted to make 4, pasted again to make 6, and pasted again to make 8.
Exponential MIC (MIC$_{exp}$) 7 *47s*	As with DAC, but once the second copy is in place both are fenced, copied and pasted to make 4. The 4 are then fenced, copied and pasted to make 8.

A GOMS analysis was carried out to determine the efficiency of each strategy. Points for each strategy are allocated on the basis of this analysis (see Table 2). Where available the moves were assigned the length of time specified by Olson and Olson (1990). Times for moves not covered in the literature were determined from an observational pilot study. The seven strategies were classified on a seven-point scale with 1 being the least efficient and 7 being the most efficient strategy.

Results

Seven of the forty-three participants used a form of MIC during the pre-test stage, and so were excluded from the analysis, leaving thirty-six. All participants were experienced users of at least one Microsoft package, yet inexperienced with Microsoft PowerPoint.

At the pre-test stage of the experiment there were no between group differences in time taken to perform the task, strategy used and device knowledge. An overall speed up in the performance of the task was observed, and by the fifth trial a main effect of practice on completion time was approaching significance [$F(2,30)=3.082$, $p=0.06$, $MSE=405.3$] (different objects $M=69s$, same objects $M=56s$, and same objects with space $M=49s$,).

Best Strategy Used at Test

Participants were given a strategy score ranging from one (inefficient strategy) to seven (efficient strategy) for each of the five test trials (see Table 2), and for the second set of test trials undertaken at the end of the experiment (in the event that MIC was not used earlier). A between subjects three by two ANOVA found a significant main effect of practice on the best strategy used at test [$F(2,30)=7.784$, $p<0.01$, $MSE=1.6$]. No main effect of pattern was found.

A Tukey HSD test confirmed a significant difference between the different ($M=4.4$) and same ($M=5.9$) objects conditions ($p<0.05$) and between the different and same objects with space ($M=6.3$) conditions ($p<0.01$). The difference between the two same objects conditions did not reach significance. The same pattern of significant results was found when considering the best strategy used over all ten test trials.

Strategy Use Score

For each participant the sum of strategy scores over the five test trials was taken as the strategy use score, and was essentially a measure of overall efficiency. A two by three between subjects ANOVA was performed on the data, and as before a significant main effect of practice was found [$F(2,30)=6.405$, $p<0.01$, $MSE=20.6$].

A Tukey test confirmed a significant difference between the different ($M=20.2$) and same objects ($M=25.0$) conditions ($p<0.05$) and between the different and same objects with space ($M=26.5$) conditions ($p<0.01$). The two same objects conditions were not significantly different.

Discovery Trial

A significant main effect of practice (but not pattern) was found for the trial (1-10) upon which one form of MIC was first used by a participant (those that did not use MIC at any time in the experiment were given a

score of 10), $F(2,30)=13.826$, $p<0.001$, $MSE=3.7$. A Tukey test found significant differences between the different ($M=6.9$) and same objects ($M=3.5$) conditions ($p<0.001$), and between the different and same objects with space ($M=3.2$) conditions ($p<0.001$).

There was no significant main effect of pattern, although a significant interaction (shown in Table 3) was found [$F(2,30)=6.337$, $p<0.01$] between pattern and practice. Simple effects tests found practice had a significant effect where the test item was patterned [$F_A@b1(2,30)=19.400$, $p<0.01$], and pattern had a significant effect where practice trials involved drawing different objects [$F_B@a1(1,30)= 8.046$, $p<0.01$].

Table 3: The mean trial upon which MIC was first used

	Practice		
	Different Objects	*Same Objects*	*Same Objects with Space*
Patterned	8.5	2.8	2.2
Non-patterned	5.3	4.2	4.2

Device Representation and Strategy Generation

The device representation questionnaire (DRQ) provided a score, out of ten, that reflected the knowledge each participant had about the device. This measure was repeated throughout the experiment and was specific to aspects of the device central to a MIC strategy. A Spearman's non-parametric correlation between improvement in the performance of the task (difference in strategy score from test trial one to test trial five) and the improvement in DRQ score was significant ($r_s=0.384$, $p<0.05$).

A two by three between subjects ANOVA was conducted on the score for each DRQ. Before practice, scores on the DRQ did not differ between groups. Results for all DRQs administered after practice (DRQs 2-5) followed the same pattern, and so the scores were combined. No main effects of pattern and practice on DRQ score were found, however interactions between practice and pattern were significant [$F(2,30)=7.312$, $p<0.005$, $MSE=3.3$] (see Table 4).

Table 4: Average score for DRQs 2-5

	Practice		
	Different Objects	*Same Objects*	*Same Objects with Space*
Patterned	5.8	7.9	8.9
Non-patterned	8.2	6.1	5.6

Simple effects tests revealed that practice had an effect where the test item was patterned [$F_A@b1(2,30)= 4.793$, $p<0.05$]. Pattern was found to have an effect on device representation where different objects were drawn at practice [$F_B@a1(1,30)=5.340$, $p<0.05$] and where objects drawn at practice were the same with space between them [$F_B@a3(1,30)=8.005$, $p<0.01$].

The questionnaire measured understanding of two concepts central to the use of MIC. Firstly, that multiple objects with space between them can be selected at the same time by using a fence, and secondly that multiple objects can be manipulated simultaneously once selected. For each of these concepts there were five questions. The trial upon which participants reached a good understanding of these concepts was taken to be when they answered four or all five of these questions correctly. An ANOVA revealed an interaction between practice and pattern for the trial upon which participants reached a good understanding of both fencing [$F(2,30)=3.451$, $p<0.05$, $MSE=1.8$] and manipulating objects [$F(2,30)=6.843$, $p<0.005$, $MSE=1.1$]. Simple effects tests found the same pattern of significant results for manipulating objects as were found on the overall DRQ results (Table 4). Further analyses found that a good understanding of fencing was reached significantly earlier on than a good understanding of manipulating objects [$t(35)=7.402$, $p<0.001$].

Discussion

As expected, practice resulted in the more efficient performance of the task. Those in groups where practice involved the selection and manipulation of more than one item performed the task more efficiently overall, generated more efficient strategies, and did so earlier on in the experiment. Although all groups used fence, copy and paste, the manner in which they were experienced influenced strategy generation. Most importantly, repeated use of the component parts of the less superior strategy proved useful for the generation of the new strategy (MIC). In addition, the more participants understood about the device, the better the strategy that was used at test.

For the copy paste task described, the results imply that people acquired information about the device through the repeated practice of a known method. Initially a good understanding of the fence operator was gained, and then an elaborated model of manipulating multiple objects. Participants learned more than was required to merely reduce the performance time of the method, as the knowledge acquired correlated with the efficiency of the strategy generated. This finding has implications for models of practice that assume people merely re-code previously stored information. Neither Anderson's compilation (1982), nor Rosenbloom and Newell's (1986) chunking model predict the results reported here. Both models explain how an existing strategy becomes more efficient, and thus effect a speed-up, rather than how information, acquired through practice, supports strategy change. Logan's (1988) instance-based model also fails to predict the

results reported here, as an increase in the number of instances of a strategy in memory can only support shift from algorithm to memory-based processing, not the kind of strategy change reported here. The results also have implications for models of strategy change. In Shrager and Siegler's (1998) model the role of new information acquired through repeated practice is not considered as a precursor to strategy change.

Also in contrast to Anzai and Simon (1979), providing the perceptual groupings that must be made in order to use the efficient strategy had no effect on strategy generation. However, groupings did have an effect on strategy generation depending upon the practice experienced. An explanation for this interaction may be that those in the different objects group, where efficient strategies were not readily available, had a relatively high workload. Constructing the pattern may have added to the high workload of the group, and so the perceptual noticing mechanism could not make use of the pattern, and in turn the use of the efficient strategy was not prompted. Alternatively, the pattern may only be useful for generating MIC if concepts central to DAC are known, without this the pattern may serve as a distraction. Similar explanations could be offered for the interaction between pattern and practice for the amount learned about the device.

In summary, the evidence reported here suggests that repeated practice of a known method can facilitate the generation of new strategies. A possible reason for this is that practice results in the elaboration of the user's device representation, which in turn supports strategy generation. These results challenge models of learning through practice that merely increase the efficiency of existing methods, and models of strategy change that fail to account for the role of practice.

Acknowledgements

References

Anderson, J. R. (1995). *Learning and memory: An integrated approach.* New York: Wiley & sons.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*, 396-406.

Anzai, Y., & Simon, H. A. (1979). The theory of learning by doing. *Psychological Review, 86*, 124-140.

Bhavnani, S. K., & John, B. E. (1997). From sufficient to efficient usage: An analysis of strategic knowledge. *Proceedings of CHI '97*, 91-98.

Bhavnani, S. K., John, B. E., & Flemming, U. (1999). The strategic use of CAD: An empirically inspired, theory based course. *Proceedings of CHI '99*, 183-190.

Bhavnani, S. K. (in press). Strategic approach to computer literacy. *Proceedings of CHI 2000.*

Carroll, J. M., & Rosson, M. B. (1987). The paradox of the active user. In J. M. Carroll (Ed.), *Interfacing thought: Cognitive aspects of human-computer interaction.* Cambridge, M.A.: The MIT Press.

Compton, B. J., & Logan, G. D. (1991). The transition from algorithm to retrieval in memory based theories of automaticity. *Memory and Cognition, 19*, 151-158.

Crowley, K., Shrager, J., & Siegler, R. S. (1997). Strategy discovery as a competitive negotiation between metacognitive and associative mechanisms. *Developmental Review, 17*, 462-489.

Delaney, P. F., Reder, L. M., Staszewski, J. J., & Ritter, F. E. (1998). The strategy-specific nature of improvement: The power law applies by strategy within task. *Psychological Science, 9*, 1-7.

Logan, G. D. (1988). Towards an instance theory of automatization. *Psychological Review, 95*, 492-527.

Luchins, A. S. (1942). Mechanization in problem solving. *Psychological Monographs, 54*, 248.

Newell, A., & Rosenbloom, P. S. (1981). Mechanisms of skill acquisition and the power law of practice. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition.* Hillsdale, New Jersey: Erlbaum.

Nilsen, E., Jong, H., Olson, J. S., & Polson, P. G. (1992). Method engineering: From data to practice. *Proceedings of ACM INTERCHI'93 Conference on Human Factors in Computing Systems*, 313-320.

Nilsen, E., Jong, H., Olson, J. S., Biolsi, K., Rueter, H., & Mutter, S. (1993). The growth of software skill: A longitudinal look at learning and performance. *Proceedings of ACM CHI'92 Conference on Human Factors in Computing Systems*, 149-156.

Olson, J. R., & Olson, G. M. (1990). The growth of cognitive modelling in human-computer interaction since GOMS. *Human Computer Interaction, 5*, 221-265.

Rickard, T. C. (1997). Bending the power law: A CMPL theory of strategy shifts and the automatization of cognitive skills. *Journal of Experimental Psychology: General, 126*(3), 288-311.

Rosenbloom, P. S., & Newell, A. (1986). The chunking of goal hierarchies: A generalized model of practice. In R. S. Michalski, J. G. Carbonell, & J. M. Mitchell (Eds.), *Machine learning 2: An artificial intelligence approach* . Los Altos, CA: Morgan Kaufmann.

Shrager, J., & Siegler, R. S. (1998). SCADS: A model of children's strategy choices and strategy discoveries. *Psychological Science, 9*(5), 405-410.

Young, R. M., & MacLean, A. (1988). Choosing between methods: analyzing the user's decision space in terms of schemas and linear models. *Proceedings of CHI '88*, 139-143.