The Effect of Goal Constraints on Strategy Generation

Suzanne C. Charman (CharmanSC1@cardiff.ac.uk)
School of Psychology, Cardiff University, Cardiff CF10 3YG, Wales, United Kingdom

Andrew Howes (HowesA@cardiff.ac.uk)
School of Psychology, Cardiff University, Cardiff CF10 3YG, Wales, United Kingdom

Abstract

Given practice, people generate new more efficient strategies for achieving desired goals. However, some researchers have observed that even experienced users of computer systems persist with relatively inefficient strategies. One reason for these findings may be a reduced opportunity to use efficient strategies in tasks where higher goal constraints are present. In this study half of the participants completed a drawing task in Microsoft PowerPoint in which they had to design the layout of a computer room and study area; the other half completed an equivalent drawing task that involved no higher goal constraints. Those with higher goal constraints were slower to generate more efficient strategies. This can be accounted for by a reduced opportunity to use 'efficient' strategies. Experience in other computer packages and strategic knowledge also influenced strategy generation.

Introduction

When people learn a new skill they often move through a series of progressively more efficient strategies. Practicing a task does not only result in faster performance, but also leads to the generation of new strategies (Delaney, Reder, Staszewski and Ritter, 1998; Charman and Howes, 2001). For example, Charman and Howes (2001) found that people can successfully generate more efficient drawing strategies when using Microsoft PowerPoint as a result of practice on component procedures.

However, Carroll and Rosson (1987) observed that the skills of computer users "tend to asymptote at relative mediocrity" (p.1). Similarly, Bhavnani and John (1997) reported that even after a number of years of experience and formal training in a computer aided design package, many users had not adopted more efficient strategies. The reason, they suggest, was not related to the standard of interface design or experience with the package, but to an absence of strategic knowledge. Bhavnani, John and Flemming (1999) found that people stay with inefficient methods unless they are taught efficient strategies explicitly.

One explanation for the conflicting observations of Charman and Howes (2001) and Bhavnani and John (1997) is that participants had different primary goals. Whereas the task used by Charman and Howes (2001) involved participants reproducing simple pictures in Microsoft PowerPoint, Bhavnani and John (1997) observed CAD users completing real work tasks, which would have imposed higher goal constraints. It is possible that the presence of higher goal constraints inhibits the generation of more efficient strategies and/or reduces the opportunity to use them. Higher goal constraints when preparing a report or presentation, for example, might concern syntax and semantics, and when designing a building they might concern functionality and aesthetic quality.

Higher goal constraints may hinder strategy generation by changing the user's focus. This is consistent with the observations of Carroll and Rosson (1987). They found that people were unwilling to take time out to read a manual because they were 'end-product' focused, i.e. their paramount concern was with completing the tasks at hand. It is possible that Bhavnani and John's (1997) participants failed to generate more efficient strategies because they were focused on meeting higher goal task constraints derived from the work domain. The focus in Charman and Howes' (2001) study however was on the method for which more efficient strategies were available.

In addition, the presence of higher goal constraints may reduce the opportunity to use efficient strategies. When taking into consideration higher goal constraints, sub-goals tend to be smaller, and so strategies that exploit the iterative power of the computer package are not as beneficial. When working with higher goal constraints computer users may generate strategies that are efficient given the sub-goal structure of the task, but which appear inefficient when viewed from the perspective of the end product. E.g. It is possible to imagine an efficient way of drawing a *given* floor plan, but when a person is *designing* a plan they do so interactively, using the device as repository for partial solutions.

While, substantial efforts have been made to model strategy change (e.g. Shrager and Siegler, 1998), these models do not address the issue of *when* people deploy strategy generation mechanisms. These models instead have addressed details of the mechanisms by which new strategies are generated from existing strategies. For example, Crowley, Shrager and Siegler (1997) proposed that people use both a metacognitive and an associative mechanism. The metacognitive mechanism is of particular interest here because it requires deliberate and resource intensive problem solving. Our interest in this paper is in the extent to which higher goal constraints moderate ability or opportunity to beneficially deploy metacognitive problem solving.

We predict that there will be a negative impact of higher goal constraints on the generation of efficient strategies. In the following experiment, whether or not participants had a higher level goal to meet was manipulated. The higher-goal task was to design the layout of a computer room and study space. In the no-higher-goal task participants copied and pasted an equivalent number of computers and desks into a large blank area. To complete the tasks a range of strategies varying in efficiency, with the same component procedures, could be used. Participants could copy and paste just one item (a computer or a desk) at a time, or could copy and paste multiple items at once. Previous experience and strategic knowledge were also examined as factors affecting strategy generation.

Method

Participants

Twenty-four undergraduates who were regular computer users, ranging in age from 18 to 26, took part in the experiment for 1½ hours of course credit or for payment of £6. All participants were given the same amount of credit or payment to take part in the study, no matter how long they took, in order to encourage efficient completion of the tasks.

Design

The study involved three between-subjects factors. The first was task type. In one condition participants were given a higher goal, where they were asked to design the layout of a computer classroom and a study area (see Appendix I). This higher goal gave rise to several design constraints that determined the manner in which the desks and computers could be arranged. The goal for these participants was to take into consideration the constraints outlined and also to consider the best use of space. In another condition participants did not have a higher goal in mind, they were asked to copy and paste an equivalent number of computers and study desks into a large blank space. A median split (over both task type conditions) on two pre-test measures, experience and strategic knowledge, created two more between subjects factors.

Procedure and Materials

The participants completed an informed consent form and then a short online spatial IQ test (Crampton and Jerabek, 2000), which consisted of ten questions, giving a score out of 100. Participants were then asked to complete a short questionnaire that asked about prior experience with Microsoft PowerPoint, as well as other software packages with drawing functions and Microsoft Word. The tuition phase was then completed, which ensured that the participants mastered basic drawing skills (drawing, moving, altering, fencing to select, copying and pasting a single shape). 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 working with more than one item at a time were included. Five questions related to fencing multiple shapes with space between them and five related to the manipulation of multiple shapes.

The participants then completed a pre-test stage where they were asked to draw eight 2-shape items in as few moves as possible (Figure 1). The strategy used by the participant was coded and scored (1-7) according to the relative efficiency of the strategy based upon the coding framework outlined in Charman and Howes (2001). For example, participants were given a score of 1 if they drew each shape one by one, and a score of 7 if an exponential copying strategy was used (exponentially increase the number of items made each time copy and paste are used). This score was taken as a measure of strategic knowledge.

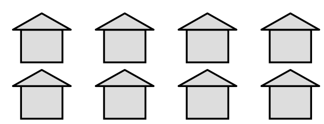

Figure 1: Pre-test task.

The main task of the experiment was then conducted. Participants were informed that there was an online help facility that they could choose to consult if they wished (this was available freely to the participants and could be accessed by selecting an open Internet Explorer window). For the main task, the no-higher-goal condition participants were given a key with sample desks and computers in it, and asked to reproduce 54 study desks and 148 computers in the space provided. The participants were all instructed that they could fence (to select), copy and paste the computers and study desks provided in the key.

In the higher-goal condition, participants were asked to plan the layout of a new extension to the Psychology building (Appendix I). In the proposed extension there was a study area where study booths were to be placed, and a computer classroom where computers were to be placed. Participants were given design constraints for which visual measures were provided, such as making sure that there were gangways, access to desks and space between computers. Although participants were told that a design could include 148 computers and 54 desks, the task was over when the participant felt they had finished their design, with the constraints met.

Participants were instructed to complete the task in as few moves as possible. Finally participants filled in another device representation questionnaire. Microsoft PowerPoint 97 was used to carry out the drawing tasks.

Strategies

To complete the task, several strategies could be employed. It was possible to work with an individual shape, as the composite parts of each item (a computer or desk) were not grouped together. A better way to complete the task was to draw a fence around one item and then copy, paste and move the item. An even better strategy was to work with more than one item at a time. In order to do this a participant needed to know that multiple items with space between them could be selected at once (by drawing a fence around them, see Figure 2) and then manipulated (copied, pasted and moved) simultaneously. Finally, the exponential copying strategy allowed very fast completion of the task. Here the number of copies produced at once increases exponentially.

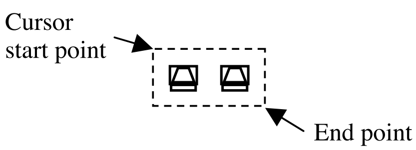

Figure 2: Fencing, by using the mouse to click and drag from the start point and releasing at the end point.

Results

Each move made by a participant was recorded, allowing a fine-grained analysis of performance. An individual move was taken to be either a key-stroke (e.g. delete) or a purposeful mouse-click (e.g. copy or select shape). Creating a fence was also counted as one move (although to do this one must click and drag).

Using efficient copying strategies did save time. The total time taken was negatively correlated with the proportion of moves where multiple items were worked with at once (r_s=-0.672, p<0.001). Only three participants visited the on-line help facility, for less than forty seconds each, so these results are not included in the analyses.

For analysis, participants were split into high and low experience groups based upon the experience questionnaire data, and also high and low strategic-knowledge groups based upon the pre-test strategy score achieved. The main analysis used was a between subjects 2x2x2 ANOVA with task type, experience and strategic knowledge as factors.

Task Type

Total Moves Those in the no-higher-goal condition (M=116.8) made fewer moves in total than the higher-goal condition (M=323.2) [F(1,16)=51.168, p<0.001, MSE=7916.1], and took fewer moves to make each item (M=0.6) than those in the higher-goal condition (M=1.9) [F(1,16)=37.444, p<0.001, MSE=0.4].

Excess Moves as a Proportion of Total Moves The fact that there were fewer moves made in the no-higher-goal condition may have been due either to reduced opportunity or to task focus. In order to further investigate strategy change as a function of opportunity we analyzed the excess moves as a proportion of total moves. For each task type the mean optimal number of moves was calculated (145 for higher-goal; 46 for no-higher-goal) and subtracted from each participants total number of moves to give the excess moves. The excess moves as a proportion of the total moves made was then calculated for each participant. There was no significant difference between the higher-goal group (M=0.45) and the no-higher-goal group (M=0.49) [F(1, 16)=0.363, p=0.555, MSE=0.05].

Strategy Generation Higher goal constraints impacted upon how soon strategies were generated. Participants occasionally started to complete the task by working with individual shapes. Most however started working with one item (computer or a desk) at a time. A better strategy was to work with more than one item at a time. The move on which this strategy was first used was recorded. The higher-goal condition (M=197.9) worked with more than one item significantly later on than those in the no-higher-goal condition (M=41.0), F(1,16)=18.729, p<0.001, MSE=17227.6.

The final progression in strategy use was to use an exponential copying strategy. A main effect of task type on the move when this strategy was first used was found [F(1,16)=13.820, p<0.01, MSE=21072.3]; those with a higher goal (M=229.8) generated the strategy later on than those with no higher goal (M=85.2).

However, while in both tasks the earliest opportunity to use each of the strategies was the same (move 7), the overall opportunity to use the strategies differed between tasks. These results may therefore reflect either reduced opportunity or a different task focus.

Experience

At the start of the experiment participants had either no experience, or very little experience, with the drawing functions in Microsoft PowerPoint.

Table 1: Interaction between task type and experience.

	High-Experience		Low-Experience	
Measure	*Higher-Goal*	*No-Higher-Goal*	*Higher-Goal*	*No-Higher-Goal*
Total time taken to complete the task	1060.5	384.3	1630.7	458.2
Total moves taken to complete the task	279.0	116.0	750.0	118.0

Performance A median split placed participants in either a high-experience or low-experience group, based upon their experience questionnaire score.

A main effect of experience on time taken to perform the task was found [$F(1,16)=18.102$, $p<0.001$, $MSE=57457.4$]. Unsurprisingly those with high experience ($M=696.4$s) performed the task faster than those with low experience ($M=1097.7$s). High-experience participants ($M=191.2$) also performed the task using fewer moves than those in the low-experience group ($M=254.0$), $F(1,16)=9.395$, $p<0.01$, $MSE=7916.1$.

Strategy Generation More interestingly, experience had an effect on how soon efficient strategies were generated. There was a main effect of experience on the move participants first worked with multiple items [$F(1,16)=7.024$, $p<0.05$, $MSE=17227.6$]. High-experience participants generated this strategy ($M=87.1$) earlier than those who had low experience ($M=157.7$). Those with high experience ($M=122.2$) also generated the exponential copying strategy earlier than those with low experience ($M=199.3$), $F(1,16)=5.856$, $p<0.05$, $MSE=21072.3$.

Strategic Knowledge

Performance A median split placed participants in either a high-strategic-knowledge or low-strategic-knowledge group, based upon their pre-test strategy score. A main effect of strategic knowledge [$F(1,16)=19.321$, $p<0.001$, $MSE=7916.1$] found that high-knowledge participants ($M=199.3$) performed the task using fewer moves than those in the low-knowledge group ($M=240.8$).

Interactions

There was a significant interaction between experience and task type for the total time taken to perform the task [$F(1,16)=12.906$, $p<0.01$, $MSE=57457.4$] and also for the total number of moves taken to perform the task [$F(1,16)=7.956$, $p<0.05$, $MSE=7916.1$] (see Table 1). Simple effects tests revealed that where experience was low, the presence of higher goal constraints had an effect on the time taken [$F_{B}@a2(1,16)=6.575$, $p<0.05$] and moves made [$F_{B}@a2(1,16)=11.457$, $p<0.05$]. Simple effects tests also found that experience had a greater effect on time taken [$F_{A}@b1(1,16)=8.350$, $p<0.05$] and moves made [$F_{A}@b1(1,16)=12.382$, $p<0.05$] where participants were given a higher goal. However, this interaction may have been due to a ceiling effect in the performance of the no-higher-goal condition.

Similarly there was an interaction between task type and strategic knowledge (see Table 2) for the number of moves taken to complete the task [$F(1,16)=7.544$, $p<0.05$, $MSE=7916.1$]. Simple effects tests revealed that strategic knowledge had a greater effect where participants were given a higher goal to consider [$F_{A}@b1(1,16)=4.509$, $p<0.05$]. However, again this interaction may be due to a ceiling effect.

Table 2: Total moves taken to complete the task.

	High-Strategic-Knowledge	Low-Strategic-Knowledge
Higher-Goal	262.6	444.3
No-Higher-Goal	72.5	139.0

Spatial IQ

A regression found that spatial IQ had a significant influence on the total number of deletes and undos used by a participant, ($\beta=-0.477$, $p<0.05$). This suggests that those with a high spatial IQ perform the task more accurately than those with a low spatial IQ, and therefore do not need to undo or delete as often. Those with a high spatial IQ may be better able to plan their actions, and so make fewer mistakes.

Mental Representation of the Device

The amount of experience a participant had on other drawing packages had a significant influence on their first device representation questionnaire score ($\beta=0.554$, $p<0.01$). A regression found that a participant's score on the first device representation questionnaire (DRQ) had a significant influence on the time taken to perform the pre-test ($\beta=-0.484$, $p<0.05$). The score that participants gained on the first DRQ also exerted influence on early improvement in the number of moves made to make each item in the main task ($\beta=0.611$, $p<0.01$).

From these data we can suggest that previous experience allows more accurate hypotheses about the operation of the device to be developed while the participant answers the questionnaire. This representation then supports the generation of faster and more efficient methods.

Case Study

One case study demonstrated a particularly strong effect of having a higher goal. Initially the participant had low device knowledge, but had an average spatial IQ and previous experience with computer packages. The participant completed the pre-test task very quickly and used a very good strategy. The strategy used in the pre-test involved the participant fencing, copying and pasting four items at once. However during the main task where the participant had to design the layout of the computer room and study areas, he did not use this strategy or the exponential copying strategy. Instead he fenced, copied and pasted each item one by one, this taking him 417 moves (*M*=220) and 1465 seconds (*M*=880). In this case it seems that the presence of a higher goal actually inhibited the use of a known and previously used strategy.

Discussion

When higher goal constraints were present participants made more moves and generated new strategies more slowly. Those with higher goal constraints made at least four times as many moves before generating more efficient strategies. In addition, those with low strategic knowledge or experience suffered diminished performance and took nearly twice as long to generate efficient strategies.

Our analysis indicated that the effect of higher goal constraints was entirely due to the way in which the design task reduced the opportunity for the use of the more efficient strategies. Once opportunity was accounted for, higher goal constraints had no significant effect on the number of moves made. This suggests that higher goal constraints might not change the ability of a user to generate an efficient strategy, rather they may change the problem such that the opportunity to use efficient strategies is reduced. Users with a higher goal may have demonstrated adaptivity to opportunity.

As opportunity could account for the difference in performance between the higher-goal and no-higher-goal conditions, we found no evidence that a higher work goal might inhibit strategy generation. We found no support for the hypothesis that users become so focused on meeting higher goal constraints that they do not concern themselves with the efficiency of the methods by which they complete the task. However, further study is required to assess the extent to which strategy generation might be inhibited by focus on higher goal constraints when opportunity is held constant.

We also found no evidence that higher goal constraints inhibited users from taking time out to learn about the device (following from Carroll and Rosson, 1987), as participants very rarely used the on-line help and all groups concluded the experiment with similar levels of device knowledge. More importantly, all the strategies were composed of the same known component procedures.

While the rate at which participants generated new strategies was slowed by a reduction in opportunity in the higher-goal condition, most participants showed a marked improvement in the efficiency of the strategies that they were using as the experiment progressed. Further, as participants made little use of the on-line help and did not stop performing the task to explore the package, the acquisition of device knowledge must have occurred while the task was being completed.

Together, our results suggest that it may be necessary to qualify the claim that people are unwilling to take time out learn (Carroll and Rosson, 1987). Our findings, while laboratory bound, indicate that people are willing to invest in the generation of more efficient strategies within the bounds of what they discover while using the device. They may not go to a manual, but they do think about the way that they achieve tasks, they do attempt to explain what they observe, and they do adapt their methods accordingly.

Finally, our findings suggest that Bhavnani, John and Flemming's (1999) conclusion that people do not generate efficient strategies without instruction may be premature. Our participants generated efficient strategies within the bounds of what the higher goal constraints allowed. These findings suggest that it may be beneficial, instead of teaching strategies explicitly, to encourage strategy generation during task performance. While Bhavnani, John and Flemming (1999) argue that strategies need to be taught, it may be better, in the long term, to ensure that users actually generate the strategy themselves. Evidence in the psychological literature suggests that there are substantial advantages to self-generation and self-explanation (Chi, Bassok, Lewis, Reimann and Glaser, 1989; Bielaczyc, Pirolli and Brown, 1995).

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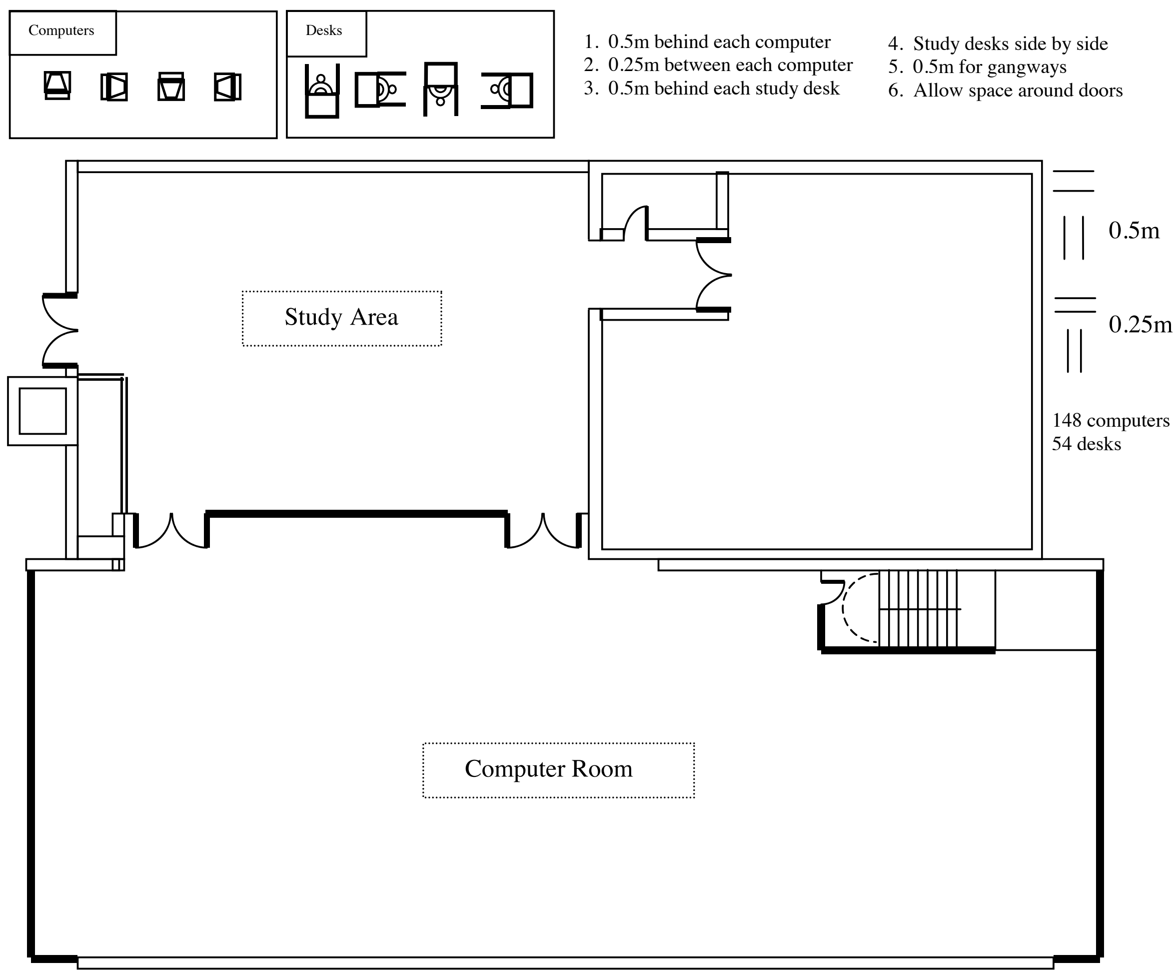

Appendix I: The higher goal task. Participants were required to plan the layout of the computer room and study area using the items provided in the key.