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The Adaptive User: An Investigation Into the Cognitive and Task Constraints on the Generation of New Methods

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When people use a computer application, they have the opportunity to adapt the methods or strategies that they deploy to better fit the demands of the task. In Experiment 1, we demonstrated that the generation of methods is limited by, but not entirely prevented by, the reduced opportunity that is associated with the iterative nature of typical computer-based tasks. In Experiment 2, we demonstrated that the cognitive demands associated with task-related problem solving delay, but do not prevent, the generation of more efficient device strategies. We argue that people are rather good at adapting device strategies to task demands and that previously reported arguments to the contrary are premature.

One aspect of intelligent behavior is the ability to generate and select behaviors that are most likely to achieve the highest payoffs at the least cost (Anderson, 1990). Indeed, the notion of people as adaptive decision makers is fundamental to cognitive science (Simon, 1975). Therefore, it seems reasonable to assume that, through experience with a computer application, people would adapt the methods by which they achieve tasks to better fit the demands that they perceive to be important. People do the best they can, with what they have, in the time available to them.

However, it has long been known that even very skilled users do not make full use of the functionality that computer applications provide (Carroll & Rosson, 1987; Lee & Barnard, 1993; Nielsen, Mack, Bergendoff, & Grischkowsky, 1986; Young & MacLean, 1988). Carroll and Rosson (1987) observed that the skills of computer users “tend to asymptote at relative mediocrity” (p. 1). They argued that this is, in part, due to the conflicting task demands that are placed on computer users. In particular, they observed that computer users have an “assimilation bias” and a “production bias.” They have an assimilation bias because of a preference for interpreting new situations in terms of old ones, and they have a production bias because of a primary goal that concerns throughput (people need to achieve their current work goals quickly and so do not take time to learn how to use the device more efficiently). Importantly, Carroll and Rosson viewed these biases as rational responses to the broader task environment in which computer users work. If people do not make full use of device functionality, then it is because they satisfice in order to balance the competition for limited resources from multiple sets of task demands. Carroll and Rosson argued that the best way to approach these biases is to find ways of reducing the costs of learning (e.g., learning from manuals) by accepting that users have more important goals than learning about a computer application and honing the instructional material accordingly.

Bhavnani and John (2000) reported a series of studies in which they found that even with formal training and many years of experience, users of computer-aided design (CAD) packages do not use the most efficient methods made available to them by the device (see also Bhavnani & John, 1997). Bhavnani (2000; Bhavnani, Reif, & John, 2001) found that although skilled users knew basic methods for copying and pasting subparts of a drawing, they did not combine these into efficient strategies by, for example, aggregating several items before copying them. Bhavnani and John (1996) argued that this inefficiency remained because the quality of work produced was still high regardless of the strategy used, and so inefficiencies in methods were not detected. In contrast to Carroll and Rosson (1987), Bhavnani, John, and Flemming (1999) suggested an intervention consisting of a classroom course rather than attempting to create instructional materials that are designed to operate within the work environment. In this course they taught both “learning to do” (traditional command-based knowledge on how to use efficient strategies) and “learning to see” (how to recognize the opportunity to use a strategy) aspects of strategic knowledge.

Bhavnani and John’s (1997, 2000) observations go beyond Carroll and Rosson’s (1987) and point to a lack of skill development for methods that should be possible for people to acquire without recourse to instruction or, indeed, to manuals. Their observations might be considered surprising given examples in the literature of how people naturally improve performance with practice. First, it is known that the time required to perform a method improves with practice; moreover, it improves according to a power law (Seibel, 1963). It is also known that although this performance may plateau as component skills are acquired, repeated trials do lead to faster performance (Bryan & Harter, 1899). In addition, with experience, people change the strategies with which they achieve problem-solving tasks (Anzai & Simon, 1979; Delaney, Reder, Staszewski, & Ritter, 1998; Rickard, 1997). Changes in strategy go beyond the coding of increasingly specialized memory chunks observed and modeled by Newell and Rosenbloom (1981) to changes in the methods, algorithms, or procedures

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Some of the data from Experiment 1 were presented at the annual meeting of the Cognitive Science Society, Washington, DC, August 2002, and a preliminary report is in the conference proceedings (Charman & Howes, 2002).

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used to perform a task. As Bryan and Harter (1899) indicated, differences in performance time may reflect increased speed in the performance of skill or may reflect differences in strategy. Changes in strategy are sometimes made to save just a few hundreds of milliseconds on frequently used tasks (Gray & Boehm-Davis, 2000).

Charman and Howes (2001) provided another example of how people spontaneously adapt routine computing skills with practice. They found that the repeated practice of a component method (a simple copy–paste method) facilitated the generation of new strategies. Charman and Howes (2001) also found evidence that practice resulted in the elaboration of the user's device representation, which in turn supported strategy generation. In Charman and Howes' (2001) study, more efficient strategies were generated by nearly all of the participants within the short time period allowed for the experiment (approximately 45 min). Therefore, although strategy adaptation may not occur in the kinds of tasks observed by Bhavnani and John (1997), people in a laboratory setting have been observed to spontaneously adapt skills in the face of competence. It seems that people are more likely to generate efficient strategies while performing laboratory tasks than they are while performing real work tasks.

This reduction in efficiency may be due to the higher goals that motivate real work. For the most part, when people use a computer, they do so to achieve some goal that has meaning to their broader personal or work-related objectives. In the context of computer method acquisition, we refer to these goals as *higher goals* and say that they impose higher-goal constraints on the use of computer applications. Higher goals in the preparation of a report or presentation, for example, might concern syntax and semantics, and in the designing of a building, they might concern functionality and aesthetic quality. The conflict between the observations of Charman and Howes (2001) and Bhavnani and John (2000) seems to suggest therefore that the efficiency of interaction with an application is reduced by the presence of higher-goal constraints.

One way in which higher-goal constraints may reduce strategy generation is by reducing the opportunity to use what would otherwise be more efficient strategies. In a design task, such as those studied by Bhavnani and John (1997, 2000), the device is used to gain feedback on the design so far and to aid with planning. Each subgoal therefore gives less potential for efficiency gains than a circumstance in which the desired end-state is known prior to the commencement of the task (as was the case in the tasks studied by Charman and Howes, 2001). When working with higher-goal constraints, users may generate strategies that are efficient given the subgoal structure of the task but that appear inefficient when viewed from the perspective of the end-product. For example, it is possible to imagine an efficient way of drawing a given floor plan, but when a person is designing a plan he or she does so interactively, using the device as a repository for partial solutions.

A second possibility is that working toward a higher goal may delay the use of efficient strategies as a consequence of focusing the user on the higher goal rather than on the device goals and thereby reducing the deployment of the cognitive mechanisms required to generate strategies. Following from Carroll and Rosson (1987), it is possible that when people are focused on throughput, not only are they less likely to take advantage of instruction, but they may also be less likely to reason about the efficiency of the methods that they already know. This possibility is supported by theories of strategy generation in the cognitive psychological literature (Crowley, Shrager, & Siegler, 1997). Crowley et al. (1997) proposed that people use both a metacognitive and an associative mechanism to generate new strategies. The associative mechanism governs an implicit ongoing process that generates new strategies by detecting repetitions and redundancies in existing methods. Conversely, the metacognitive mechanism governs an explicit problem-solving process that generates new strategies by searching the space of possible methods. The metacognitive mechanism is of particular interest here because it uses deliberate and resource intensive problem solving and because the problem solver has choice over when and to what problems it is deployed. It is possible that the time and resources required to use the metacognitive strategy generation mechanism are simply not available when higher-goal constraints are present.

We report two experiments in this article. In both, we investigated the hypothesis that the presence of higher-goal constraints delays strategy generation in a CAD-like task (that involved arranging the layout of a computer laboratory and study room). We were interested in the use of strategies for copying multiple items. Figure 1 illustrates three possible strategies for constructing a drawing using the functions fence (to select), copy, and paste. In Experiment 1, we focused on the possibility that opportunity to use

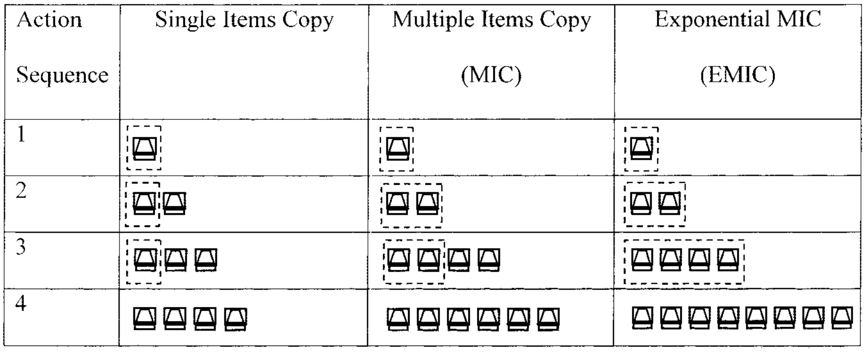


Figure 1. Three strategies for the completion of the main task. The product at the end of each action sequence is displayed. Items surrounded by a dashed line are selected and stored in a buffer by copying and then are pasted.

strategies is reduced when a higher goal is present. In Experiment 2 opportunity was held constant to examine the prediction that the presence of a higher goal would reduce the use of strategy-generation mechanisms.

Experiment 1

In the following experiment, participants either completed a task with a higher goal or a task with no higher goal. We predicted that there would be a negative effect of higher-goal constraints on the generation of efficient strategies and task performance. The higher-goal task was to design the layout of a computer room and study area according to a set of given constraints. In the task in which there was no higher goal, participants were asked to copy 148 images of computers and 54 images of desks into a large blank area. No other constraints were specified. 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, copy and paste multiple items at a time (multiple items copy; MIC), or increase the number of items produced with each copy exponentially (exponential multiple items copy; EMIC).

Method

Participants

Twenty-four undergraduates, who were regular computer users, ranging in age from 18 to 26, took part in the experiment for 1.5 hr of course credit or for payment of £6 ($9.26). All participants were given the same amount of credit or payment to take part in the study, no matter how long they took, to encourage efficient completion of the tasks.

Design

The study involved one between-subjects factor, which was Task Type. In one condition, participants were given a higher goal in which they were asked to design the layout of a computer classroom and a study area. 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 complete a design while taking into consideration the constraints. In the other condition, participants were not given a higher goal; instead they were asked to copy and paste an equivalent number of images of computers and study desks into a large blank space.

Materials and Procedure

An introductory tutorial on Microsoft PowerPoint was completed, during which participants were able to practice drawing shapes and during which they fenced, copied, and pasted a single shape. The participants were asked only to use functions identified in the tutorial for making copies of shapes so that comparison of the number of actions could be made more accurately. Functions in the tutorial included, for example, fence, copy, and paste, but the functions of duplicate and group were excluded. All the tasks completed by the participants were carried out on Microsoft PowerPoint ‘97, and participants’ on-screen moves were videotaped.

After the tutorial phase, the main task of the experiment was completed. For the main task, the participants in the no-higher-goal condition were given a key with sample desks and computers in it and were asked to reproduce images of 54 study desks and 148 computers in the blank space provided. In the higher-goal condition, participants were asked to plan the layout of a new extension to the psychology building. In the proposed extension there were two rooms: a study area where study booths were to be placed and a computer classroom where computers were to be placed (see Figure 2). Participants were given a number of design constraints to consider. First, they were told that each computer and desk should have a distance of 0.5 m behind them for access. Second, they were told that study desks should be side by side. Third, they were told that computers should have a space of 0.25 m between them to provide room for books and files. Finally, participants were asked to make sure that there were appropriate gangways of 0.5 m and that desks and computers were not placed immediately in front of doors. When participants were required to space items by a certain amount, visual measures were provided. Although participants were told that a design could include a possible 148 computers and 54 desks, the task was over when participants felt they had finished their design, with each of the constraints met. The participants were all instructed that they could fence (to select), copy, and paste the images of the computers and study desks provided in the key. To encourage efficient performance of the task, all participants were instructed to complete the task in as few moves as possible.

The main tasks could be completed using a number of strategies, with these varying in efficiency (see Figure 1). The participants could fence, copy, and paste single items (a computer or a desk); they could fence, copy, and paste multiple items simultaneously (MIC); and they could increase the number of items produced at once exponentially (EMIC). To use the more efficient strategies, a participant had to understand that more than one item could be fenced (see Figure 3) and therefore could be selected, copied, and pasted at once.

Results

Data from this experiment were analyzed using *t* tests. We predicted a negative effect of a higher goal on performance and strategy generation. The distributions of the dependant variables, actions and generation of MIC and EMIC, were all significantly skewed according to the criterion (skewness statistic/standard error of skewness [SES] should not exceed 1.96) provided by Howitt and Cramer (1997). Actions and generation of EMIC were transformed using a square-root transformation and the more negatively skewed variable generation of MIC was transformed using a $\log_{10}$ transformation. Following these transformations the variables had acceptable levels of skew and kurtosis. The full results are in Table 1, which presents the descriptive statistics and *t* tests for the transformed data.

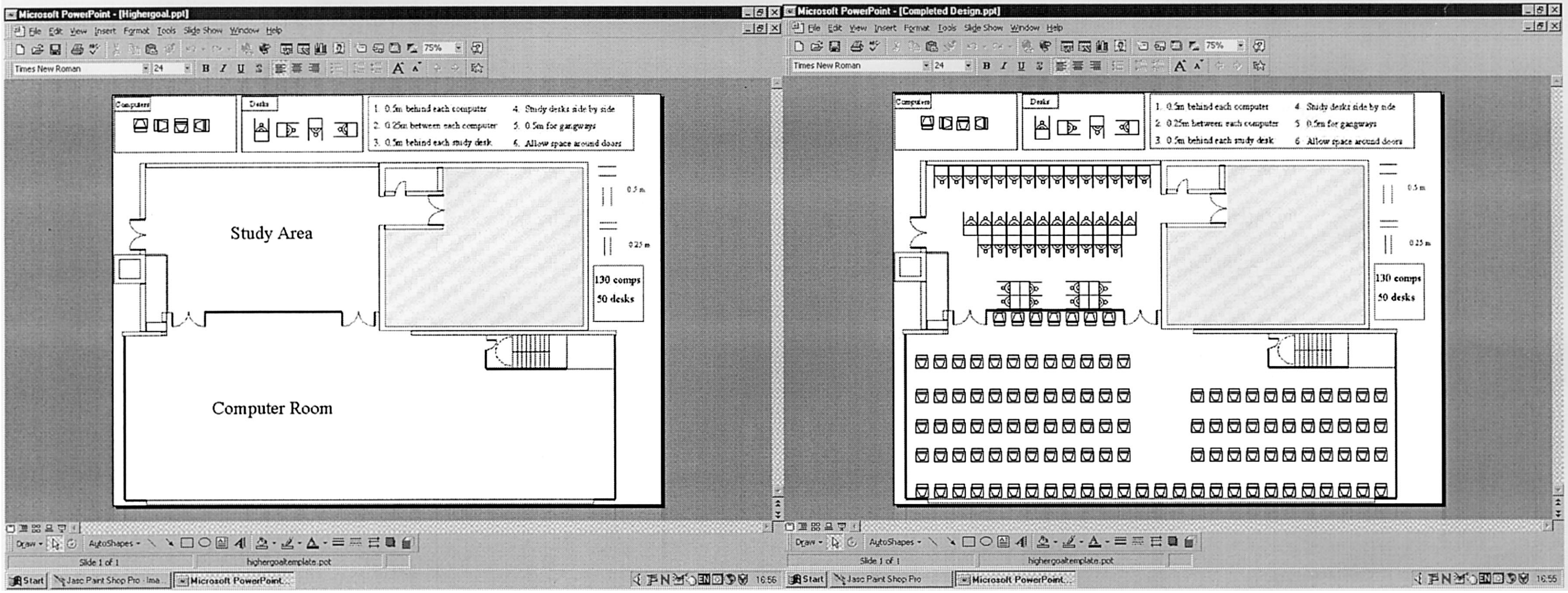
Actions

Each action made by a participant was recorded. A keystroke (e.g., delete), a purposeful click of the mouse (e.g., copy or select shape), or a fence (click, hold, drag, and release) were each counted as one action. A between-subjects *t* test found that those in the no-higher-goal condition made fewer actions in total than did those in the higher-goal condition.

Strategy Generation

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 action for which a participant first used this strategy was recorded. The higher-goal participants first worked with more than one item on a significantly later action than did those in the no-higher-goal condition.

The final progression in strategy use was to use an exponential copying strategy. The move on which this strategy was first used



1. 0.5m behind each computer
2. 0.25m between each computer
3. 0.5m behind each study desk
4. Study desks side by side
5. 0.5m for gangways
6. Allow space around doors

Figure 2. Screen shot of the higher-goal design task (left) and an example of a completed design (right).

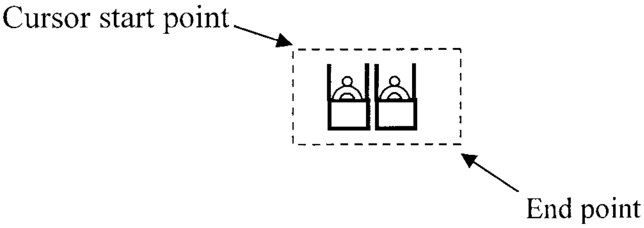


Figure 3. Fencing to select multiple items; using the mouse to click and drag from the start point and releasing at the end point.

was recorded. A between-subjects *t* test found that there was no significant difference between the higher-goal group and the no-higher-goal group. According to effect sizes found in previous work (Charman & Howes, 2001; Cohen's *f* was greater than .40, Cohen's *d* was greater than .80), we expected to find large effects in the present study. With the current sample, the probability of rejecting the null hypothesis, where there is a large effect ($d = .80$ according to Cohen, 1977), is only .46. According to Cohen (1977), to accept the validity of the null hypothesis, a nonsignificant comparison test must have a power of .80 or above. Therefore, although the difference between the two groups did not reach significance, we cannot assert the validity of the null hypothesis.

Excess Actions as a Proportion of Total Actions

The finding that there were fewer actions made in the no-higher-goal condition may have been due either to reduced opportunity to use efficient strategies or to delayed ability to generate efficient strategies. To investigate strategy change as a function of opportunity, we first calculated the mean optimal number of actions for each task type (145 for higher-goal; 46 for no-higher-goal) and then subtracted this from each participant's total number of actions to determine the excess actions made by each participant. We then analyzed the excess actions as a proportion of the total actions for each participant. There was no significant difference between the higher-goal group and the no-higher-goal group. Although the lack of a difference here suggests the reason for delayed strategy generation in the higher-goal group was simply due to reduced opportunity to use efficient strategies, the power of this test was low (estimated as .46). According to Cohen (1977), to accept the validity of the null hypothesis, a nonsignificant comparison test must have a power of .80 or above. Therefore, we cannot conclude that a higher goal only reduces the opportunity to use efficient strategies.

Discussion

When higher-goal constraints were present, participants took more actions to complete the task and took longer to generate the MIC strategy. Moreover, our analysis indicated that in this experiment the effect of higher-goal constraints was primarily due to the way in which the design task reduced the opportunity for the use of more efficient strategies. When participants were working toward a higher goal, they used the external device as a repository for intermediate solutions, thus facilitating the problem-solving process. The fragmentary nature of these intermediate solutions did not present the same opportunity for the use of MIC strategies as was available to participants who were simply asked to create a fixed number of items. In this instance, a delay in strategy generation may demonstrate adaptivity to the reduced opportunity to use efficient strategies.

One conclusion that might be drawn from this result is that there is no point in teaching people sophisticated copy–paste strategies because in real work contexts there is little opportunity to use them (cf. Bhavnani & John, 2000). However, it was also evident from the results of Experiment 1 that most of the participants who were subject to higher-goal constraints did start to use strategies in which they copied multiple items when given sufficient practice. Moreover, they did so with hardly any reference to instruction. Although there was a reduction in opportunity, the utility of and the ability to generate these strategies was not eliminated.

Although no evidence was found to support the view that higher-goal constraints inhibited strategy generation beyond reducing opportunity, the experiment was not optimally designed to make such observations. There was, however, some informal evidence that higher-goal constraints reduced the use of more sophisticated strategies. The behavior of one of the participants was of particular interest because the higher-goal constraints appeared to inhibit a previously used strategy. The participant used an efficient strategy in the pretest (four items were fenced, copied, and pasted at once) but during the main task reverted to copying and pasting each item one by one. This took the participant 417 actions ($M = 220.0$, $SD = 163.8$) and 1,465 s ($M = 880.3$, $SD = 588.7$). In this case the presence of a higher goal seems to have inhibited the use of a known and previously used strategy.

Table 1
t Tests for Actions, Generation of Multiple Items Copy (MIC) and Exponential Multiple Items Copy (EMIC), and Proportion of Excess Actions (Experiment 1)

Dependent variable	Condition	*M*	*SD*	*t*(22)	*d*
Actions	Higher-goal	17.48	4.37	4.67**	1.38
	No-higher-goal	10.48	2.84		
Generation of MIC	Higher-goal	1.94	0.63	3.14**	1.09
	No-higher-goal	0.89	0.97		
Generation of EMIC	Higher-goal	13.19	7.81	1.96	0.75
	No-higher-goal	8.02	4.77		
Proportion of excess actions	Higher-goal	0.45	0.24	−0.38	0.16
	No-higher-goal	0.49	0.26		

** $p < .01$.

Experiment 2

Experiment 1 showed a reduced opportunity for the use of efficient strategies when participants had a higher goal. However, the experiment left open the question of whether higher-goal constraints might delay strategy generation by inhibiting metacognitive problem solving (Crowley et al., 1997). Experiment 2 was therefore designed to hold opportunity constant across the higher-goal and no-higher-goal conditions, allowing the hypothesis that higher-goal constraints inhibit metacognitive problem solving to be tested directly.

The use of a metacognitive mechanism (Crowley et al., 1997) in strategy generation is analogous to the use of reflection in problem solving (Gaskins, 1988). The importance of self-evaluation in learning has been identified in the educational literature (e.g., Ascher, 1984; Schunk, 1983), and verbalizations have been found to be important in the traditional problem-solving literature (Ericsson & Simon, 1993). Chi, De Leeuw, Chiu, and LaVancher (1994) suggested that self-explanation gives such an advantage as it enables the integration of new information into existing knowledge. Further, Chi et al. (1994) found that this advantage still exists when self-explanations are explicitly prompted rather than spontaneous.

However, Gaskins (1988) found that people do not spontaneously self-monitor and evaluate when performing tasks. Moreover, Trudel and Payne (1996) suggested that the rapid input and low effort required to use modern display-based devices do not encourage reflection, and so learning may be reduced when using computer applications. It is conceivable therefore that the use of more sophisticated copy–paste strategies could be facilitated by encouraging people to reflect on the methods they use to achieve a task. It is surprising that this question seems to have not yet been investigated. Although previous research has been directed at understanding reflection in impasse-driven situations (i.e., situations in which the goal cannot be achieved without further problem solving; e.g., Trudel & Payne, 1996), there are no reported studies on the effects of reflection in the face of competence.

In Experiment 2, we considered two main factors—the presence of higher-goal constraints and the focus of reflections. First we examine whether there is an impact of higher-goal constraints when opportunity is matched across conditions. We hypothesized that higher-goal constraints would delay strategy generation by inhibiting the deployment of metacognitive (reflective) strategy generation mechanisms, even when opportunity for the use of more efficient strategies was the same. Second, we examined the effect of reflection. If a higher goal delays strategy generation by changing the content of reflections as hypothesized, then for those with a higher goal, reflection on methods should remove the negative effect of the higher goal on performance. We also compared reflection on the higher goal (the quality of the design) and the constraints it imposes (functionality, spacing etc) with reflection on the methods by which the task is performed. We hypothesized that reflection on the design would delay strategy generation and impede task performance in comparison with reflection on methods. We also expected to observe a reduction in knowledge learned about the device and less improvement in strategy use when reflection was centered on the design in comparison with when reflection was centered on the methods used to complete the task. If higher-goal constraints delay strategy generation, regardless of opportunity, and if the focus of reflection affects strategy generation in the manner hypothesized, then this would support the view that higher-goal constraints serve to delay strategy generation by changing the focus of the reflective metacognitive mechanism. Finally, by looking at the quality of the designs produced, in this experiment, we examined Bhavnani and John's (1996) claim that new strategies are not generated because inefficient strategies have no effect on the quality of the end-product and so remain undetected.

Method

Participants

Fifty undergraduate psychology students, ranging in age from 18 to 23, took part in the experiment. Each participant received either 1 hr of course credit or payment of £6 ($9.26) to complete the experiment.

Design

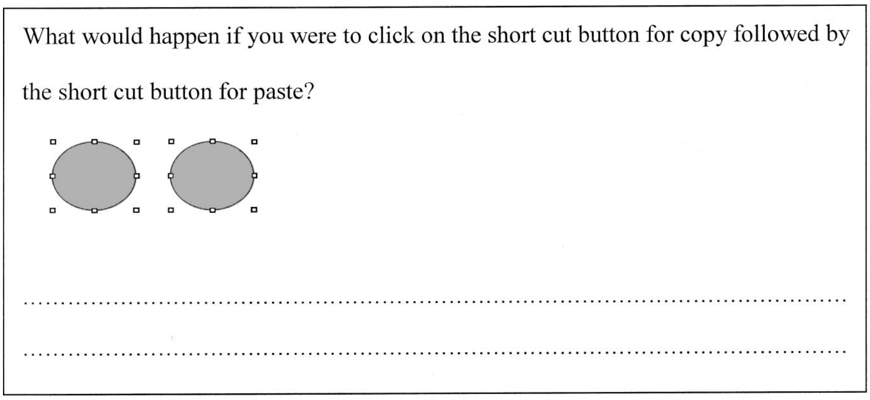
Two independent variables—the presence of a higher goal (no-higher-goal and higher-goal) and reflection (no-reflect and method-reflect)—each with two levels formed the main part of the design. A fifth condition—higher-goal, design-reflect—allowed the effect of the content of reflections to be further examined. To control for opportunity to use efficient strategies, we matched each participant in the no-higher-goal–method-reflect condition to a participant in a higher-goal–method-reflect condition; we did likewise for the no-reflect conditions. A no-higher-goal task was constructed for each participant based on the subgoals of the participant in the matched higher-goal condition (this is explained further in the *Materials and Procedure* section). The higher-goal participants experienced one of three levels of self-monitoring reflection (method-reflect, no-reflect, and design-reflect).

Materials and Procedure

Participants first filled in a device representation questionnaire (DRQ 1), which included 10 questions designed to assess task-relevant device knowledge (see Figure 4 for example question). Following the completion of DRQ 1, participants were given an introductory tutorial on Microsoft PowerPoint (as in Experiment 1). All the tasks completed by the participants were carried out in Microsoft PowerPoint '97, and participants' on-screen moves were videotaped. The participants were then given a pretest, in which they were asked to draw eight two-shape items arranged in two rows of four (see Figure 5). Performance on the pretest was coded according to the framework (see Table 2) outlined in Charman and Howes (2001).

The main task was then described to the participants. It was explained to those in the higher-goal conditions that they were to undertake a design task (as shown in Figure 2). They were asked to design the layout of a computer room and study area, using the items provided in the key. To complete the design, the participants were asked to keep in mind a number of constraints (as in Experiment 1). Apart from these constraints, the participants could design the study area and computer room as they wished. An example of a completed design task is shown in Figure 2.

In the no-higher-goal conditions, the main task was different. Each participant in the no-higher-goal groups performed a different task that was made up of the subgoals of the participant in the higher-goal group with whom he or she was matched. Each participant in the no-higher-goal groups performed an equivalent task, in terms of his or her subgoals and, therefore, in terms of his or her opportunity to use efficient methods, to the participant with whom he or she was matched in a higher-goal condition (matches were made within type of reflection). For example, if a participant in a higher-goal group completed a row of 10 desks as part of his or



What would happen if you were to click on the short cut button for copy followed by the short cut button for paste?

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Figure 4. Example question from the device representation questionnaire assessing knowledge regarding manipulating multiple items. Correct answer: As both shapes are selected, both shapes are replicated slightly below and to the right of the existing shapes.

her design, then the matched participant in the no-higher-goal group was required to complete a row of desks in a box that was just big enough for 10 desks. Figure 6 shows part of a higher-goal design and the equivalent no-higher-goal task.

All the matched subgoals were completed in exactly the same order as the participants performed the subgoals when completing the design task. If the participant in the higher-goal condition moved or deleted some items, then the matched participant was also given a subtask to move or delete the same number of items. Thus, opportunity was held constant across groups, and comparisons could be made within these matched groups. For an example of a no-higher-goal task, see Figure 7.

Participants in the no-higher-goal–no-reflect condition and the higher-goal–no-reflect condition performed the task without interruption. In the method-reflect and design-reflect conditions, the participants were interrupted every 2 min throughout the main task (design task or no-higher-goal task) and were asked a series of simple questions (see Table 3). Those in the method-reflect conditions were asked questions about the method they were using, and those in the design-reflect condition were asked questions about the design. Participants in both conditions were asked questions that involved both reviewing the design or methods so far and describing intentions for the design or methods to be used or completed in the future.

As in Experiment 1, the main task could be completed using a number of strategies, with these varying in efficiency (see Figure 1). The participants could fence, copy, and paste single items (a computer or a desk), they could fence, copy, and paste multiple items simultaneously (MIC), and they could increase the number of items produced at once exponentially (EMIC). To use the more efficient strategies, a participant must understand that more than one item can be fenced (see Figure 3) and therefore selected and copied and pasted at once.

After the main task, participants completed a posttest. This was the same task as was completed in the pretest (see Figure 5), and it was coded in the same manner as was the pretest. Finally, participants completed a second device representation questionnaire (DRQ 2), which was exactly the same as the one filled in at the start of the experiment and included questions about the package relevant to the efficient completion of the task. After the experiment was completed, the designs were rated. The items that had been placed into the design were counted (giving a measure of how well the space had been used), and then a point was subtracted for each distorted or misplaced item (according to the design constraints) and for each item blocking gangways and doorways.

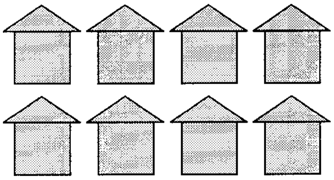

Figure 5. Items drawn in the pretest task.

Results

Actions Made and Strategy Generation

Following a one-way analysis of variance (ANOVA) on actions and strategy generation, we made three planned contrasts using the mean square error from the ANOVA. The first planned comparison was to determine whether a higher goal negatively affects actions made and strategy generation of MIC and EMIC when opportunity is held constant. We made a one-tailed planned comparison of the higher-goal–no-reflect group and the no-higher-goal–no-reflect group to examine whether there was a negative effect of a higher goal when there was no reflection intervention. Second, to ascertain whether reflection on methods significantly reduces the negative effect of a higher goal on strategy generation, we made a one-tailed planned comparison of the higher-goal–no-reflect group and the higher-goal–method-reflect group for performance and strategy generation of MIC and EMIC. Finally, we used a one-tailed planned comparison of the higher-goal–method-reflect group and the higher-goal–design-reflect group (with performance and strategy generation deficits expected for design reflect in comparison with method reflect) to test whether there was an effect of the content of reflections on actions performed to complete the task and strategy generation (of MIC and EMIC).

These planned comparisons were nonorthogonal, and so we performed a sequential Dunn–Sidák adjustment to determine what p values could be accepted as significant at alphas equal to .05 and .01. This adjustment found that with three comparisons, the smallest p value must be less than .017, the second must be less than .025, and the largest must be less than .050 in order to attain significance at an alpha equal to .05. For an alpha equal to .01, the smallest p value must be less than .003, the second must be less than .005, and the largest must be less than .01. Table 4 shows the

Table 2
Coding Framework for the Pre- and Posttest Tasks

Point awarded and strategy name	Classification requirement
1—Shape-by-shape (SBS)	Each 2-shape item is drawn shape-by-shape.
2—Division (D)	All of one of the shapes that make up the 2-shape item are completed, followed by all of the second shape.
3—Element copy (EC)	Single shapes are copied and pasted.
4—Detail aggregate copy (DAC)	All the details are completed in the first 2-shape item, then it is fenced, copied, and pasted 7 times to make 8.
5—Multiple items copy (MIC_1)	As with DAC, but once 4 copies of the picture are in place, they are all fenced, copied, and pasted at the same time to make 8.
6—Multiple items copy (MIC_2)	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.
7—Exponential MIC (EMIC)	As with DAC, but once the second copy is in place both are fenced, copied, and pasted to make 4. Then 4 are fenced, copied, and pasted to make 8.

Note. From "The Effect of Practice on Strategy Change," by S. C. Charman and A. Howes. In J. D. Moore and K. Stenning (Eds.), 2001, *Proceedings of the Twenty-Third Annual Conference of the Cognitive Science Society* (p. 191). Mahwah, NJ: Erlbaum. Copyright 2001 by the Cognitive Science Society. Adapted with permission.

means and standard deviations for each of the five groups for actions and strategy generation of MIC and EMIC, and Table 5 shows the statistics for each of the planned comparisons.

Actions. Each action made by a participant was recorded. A keystroke (e.g., delete), a purposeful click of the mouse (e.g., copy or select shape), or a fence (click, hold, drag, and release) were each counted as one action. The one-way ANOVA on actions made found significant differences across the five conditions, $F(4, 45) = 7.73$, $p < .01$, $MSE = 12256.97$, Cohen's $f = .83$. Using the mean square error from this ANOVA, we conducted planned comparisons. The first planned comparison found that those in the higher-goal–no-reflect group performed the task using more actions than did the no-higher-goal–no-reflect group. A second planned comparison found that those in the higher-goal–no-reflect group performed the task using more actions than did the higher-goal–method-reflect group. The third planned comparison found that the higher-goal–method-reflect group completed the task using fewer actions than did the higher-goal–design-reflect group.

Strategy generation. The action on which each strategy was first used was taken as a measure of strategy generation. The one-way ANOVA on the generation of the MIC strategy found significant differences across the five conditions, $F(4, 45) = 8.02$, $p < .01$, $MSE = 23692.44$, Cohen's $f = .84$. Using the mean square error from this ANOVA, we conducted planned comparisons. A planned comparison found that those in the higher-goal–no-reflect group generated the MIC strategy on a later action than did the no-higher-goal–no-reflect group. A second planned comparison found that those in the higher-goal–no-reflect group generated the MIC strategy significantly later than did the higher-goal–method-reflect group. The third planned comparison found that the higher-goal–method-reflect participants generated the MIC strategy earlier than did the higher-goal–design-reflect participants.

The one-way ANOVA on the generation of the EMIC strategy found significant differences across the five conditions, $F(4, 45) = 6.57$, $p < .01$, $MSE = 22609.49$, Cohen's $f = .76$. Using the mean square error from this ANOVA, we conducted planned comparisons. A planned comparison found that those in the higher-goal–no-reflect group generated the EMIC strategy on a later action than did those in the no-higher-goal–no-reflect group. The second planned comparison found that those in the higher-goal–no-reflect group generated the EMIC strategy later than did those in the higher-goal–method-reflect group. The third planned comparison found that the higher-goal–method-reflect participants generated the EMIC strategy earlier than did the higher-goal–design-reflect participants.

Knowledge Acquisition and Improvement in Performance

The distribution of the dependant variable, knowledge acquisition, which was calculated from the improvement in scores from

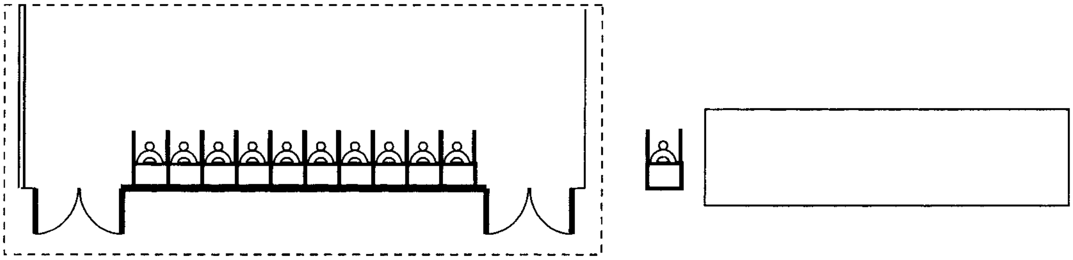

Figure 6. Higher-goal task subgoal (left) and no-higher-goal task equivalent (right).

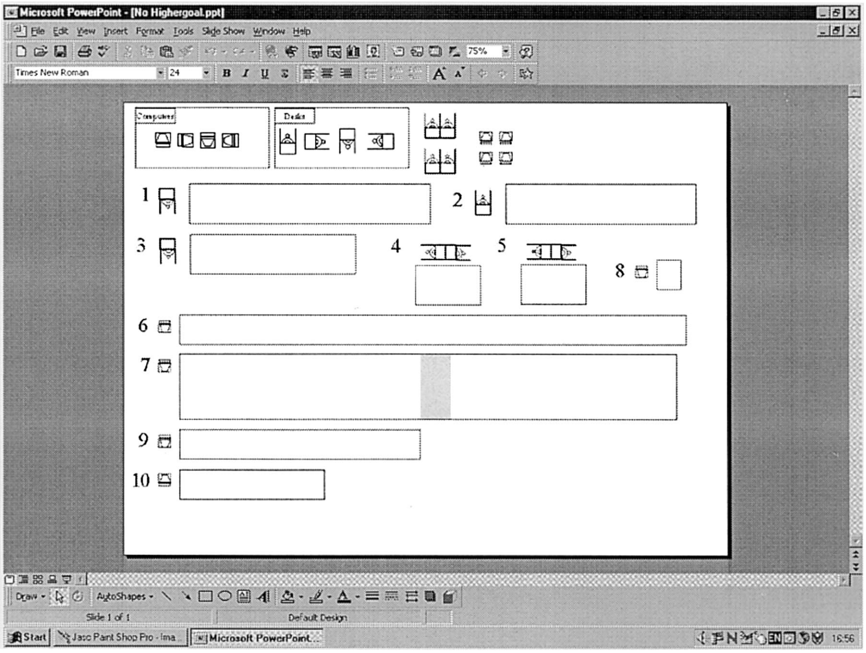

Figure 7. Screen shot of a no-higher-goal task matched to the participant that completed the design in Figure 2.

DRQ 1 to DRQ 2, was significantly skewed according to the criterion (skewness statistic/SES should not exceed 1.96) provided by Howitt and Cramer (1997). Knowledge acquisition was transformed using a square-root transformation. Following this transformation the variable had an acceptable level of skew and kurtosis. We examined the effect of the content of reflections on device knowledge acquired and improvement in performance by conducting a one-way ANOVA followed by a one-tailed planned comparison of the higher-goal–method-reflect group and the higher-goal–design-reflect group.

The one-way ANOVA on knowledge acquisition did not find significant differences across the five conditions, $F(4, 45) = 2.39$, *ns*, $MSE = .48$, Cohen's $f = .46$. With the current sample size, the probability of rejecting the null hypothesis, where there is a large effect (Cohen's $f = .40$ according to Cohen, 1977), is only .56. Therefore, although the groups did not differ significantly, we cannot assert the validity of the null hypothesis, as power is not equal to or greater than .80 (Cohen, 1977). As the omnibus test did not reach significance, the planned comparison of the higher-goal–method-reflect group and the higher-goal–design-reflect group was not conducted.

The one-way ANOVA on improvement in performance found significant differences across the five conditions, $F(4, 45) = 2.62$, $p < .05$, $MSE = 1.86$, Cohen's $f = .48$. Using the mean square error from this ANOVA, we conducted the planned comparison. A planned comparison also found that the method-reflect participants improved more in strategy use from the pretest to the posttest than did the design-reflect participants.

Table 3
Questions Asked During Reflection Episodes

Questions asked in each condition
Method-reflect condition
1. What was your last mini task as part of your design?
2. What was the last method you employed to make a computer/desk?
3. Are there any ways you can improve your method for the next time you make an item? Is there anything about how the device works that you need to remember when you continue?
4. What is your next mini task as part of your design?
Design-reflect condition
1. How neat and tidy is your design?
2. How well have you met the 6 constraints you are working to?
3. How functional is your study area for quiet study? How functional is your computer area for personal use, teaching/practical demonstrations and group work?
4. What part of your design will you work on next?

Table 4
Means and Standard Deviations for Experiment 2

	Higher-goal						No-higher-goal			
	Method-reflect		No-reflect		Design-reflect		No-reflect		Method-reflect	
Dependent variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Actions	267.20_a	111.89	372.80_b	139.39	436.50_b	131.37	247.10_a	74.11	199.10	81.16
MIC	168.60_a	157.92	281.70_b	215.92	409.30_b	164.92	92.20_a	105.00	85.20	93.16
EMIC	203.90_a	149.15	331.10_b	182.98	421.80_b	160.81	155.90_a	135.14	139.10	114.88
Knowledge acquisition	1.85	.56	1.76	.75	1.16	.54	1.82	.87	1.23	.70
Improvement in performance	2.85_a	.75	2.00	1.56	1.10_b	1.45	1.35	1.53	2.20	1.36
Quality of designs	130.90	29.25	143.30	33.05	116.30	22.12				

Note. Means in the same row that do not share subscripts differ at $p < .05$ according to planned comparisons (see Table 5). MIC = multiple items copy; EMIC = exponential multiple items copy.

Quality of Designs

The quality of the designs was assessed by taking into consideration how many desks and computers were included in the final design (one point was allocated for each item). A point was deducted for a distorted item and for each item that was not placed correctly according to the design constraints. For each missing or obstructed gangway another point was deducted, and for each obstructed doorway a point was deducted. It may be expected that reflecting on the design would have positive implications for the quality of the design produced in comparison with reflecting on methods.

The one-way ANOVA on the quality of design produced did not find significant differences across all five conditions, $F(2, 27) = 2.27$, *ns*, $MSE = 812.20$, Cohen's $f = .41$. With the current sample size, the probability of rejecting the null hypothesis, where there is a large effect (Cohen's $f = .40$ according to Cohen, 1977), is only .45. Therefore, although the groups did not differ significantly, we cannot assert the validity of the null hypothesis, as power is not equal to or greater than .80 (Cohen, 1977). As the omnibus test did not reach significance, the planned comparison of the higher-goal–method-reflect group and the higher-goal–design-reflect group was not made.

To test Bhavnani and John's (1996) claim that inefficient strategies are not detected because they have no effect on the end-product, we performed a median split on a total strategy use score for all those with a higher goal (higher-goal–method-reflect, higher-goal–no-reflect, and higher-goal–design-reflect). A two-tailed between-subjects *t* test compared the design rating for those who used efficient strategies early in the task with those who generated efficient strategies toward the end of the task or not at all. Those who generated efficient strategies early in the task produced a higher quality end-product ($M = 148.2$, $SD = 20.0$) than did those who generated efficient strategies toward the end of the task or not at all ($M = 112.2$, $SD = 27.1$), $t(28) = 4.14$, $p < .01$, Cohen's $d = 1.2$.

Discussion

Regarding participants who had no reflection intervention, those with a higher goal performed more actions to complete the task and also generated efficient strategies later on than those with no higher goal. The presence of higher-goal constraints did not stop strategy generation altogether (as the majority of participants generated both efficient strategies eventually); rather, a higher goal delayed strategy generation even though opportunity to use effi-

Table 5
Planned Comparisons for Actions, Generation of Multiple Items Copy (MIC) and Exponential Multiple Items Copy (EMIC), and Improvement in Performance

	Comparison 1: higher-goal–no-reflect vs. no-higher-goal–no-reflect		Comparison 2: higher-goal–no-reflect vs. higher-goal–method-reflect		Comparison 3: higher-goal–method-reflect vs. higher-goal–design-reflect	
Dependent variable	*t*(45)	*d*	*t*(45)	*d*	*t*(45)	*d*
Actions	2.54*	.91	2.13*	.77	3.42**	1.23
MIC	2.75**	.98	1.64*	.59	3.50**	1.25
EMIC	2.61**	.97	1.89*	.70	3.14**	1.20
Improvement in performance					2.87**	1.21

* $p < .05$. ** $p < .01$.

cient strategies was held constant across the comparison groups. Regarding participants who completed a higher-goal task, those who reflected on methods performed the task with fewer actions and generated the EMIC strategy earlier than did those who did not reflect. Reflecting on methods reduced the delay in strategy generation and reduced the negative effect on performance attributed to the higher goal. For those with a higher goal who did not reflect, the delay in strategy generation and the negative effect on performance remained. Those who reflected on methods made fewer actions to complete the task, generated efficient strategies earlier, and improved in strategy use by more than those who reflected on their design.

The content of reflections had no affect on the quality of the design produced, even though in one of the conditions the quality of the design was the subject of reflection. Participants who generated the two efficient strategies (MIC and EMIC) early in the experiment produced a better quality design in comparison with those who generated efficient strategies later in the task. It is probable that efficient strategies helped improve design quality because when several items in a design were reused, a participant only had to ensure that the original ones were placed correctly in a line. If a less efficient strategy, in which each item is made one by one, was used then there would have been more opportunity to misplace items and careful placing of items would have required more effort. If, as seems to have been the case in our experiment, efficient strategies do affect the quality of work produced, it should be possible to detect inefficient methods by examining the quality of the end-product (cf. Bhavnani & John, 1996).

Together, the results of this experiment support the hypothesis that people are less likely to generate more efficient methods for achieving computer-based tasks when they are engaged in a work-related goal (a higher goal) because they spend time thinking about the goal instead of reflecting on the methods used to achieve the goal. The results also support the hypothesis that reflection, and therefore metacognitive processing (Crowley et al., 1997) on methods, is required to generate new strategies. To this extent, the results support the observations made by Carroll and Rosson (1987): People are less likely to take time to learn when they (a) are focused on a higher-level goal and (b) have sufficient knowledge to get by. The results of the present study go beyond Carroll and Rosson's in that they explicitly concern the extent to which people generate strategies using only cognition and interaction with the device, whereas Carroll and Rosson's observations concerned the way in which people use instructional materials.

General Discussion

The hypothesis that the presence of higher-goal constraints would delay strategy generation was supported by the data in two ways. First, opportunity to use efficient strategies was reduced because of the way in which participants used the external device as a repository for intermediate results (see Experiment 1). Second, problem-solving mechanisms were engaged with the higher goal to the detriment of the reflective processing required to find more efficient strategies (see Experiment 2); even when a task with a higher goal offered the same opportunity to use efficient strategies, performance was negatively affected, and strategy generation was delayed. Furthermore, with Experiment 2, we found that interleaved reflection on methods partly removed the negative effect of the higher goal on performance and strategy generation.

In addition to supporting the experimental hypotheses, our findings are largely supportive of, and extend, the observations made by Carroll and Rosson (1987). The fact that strategy generation was delayed by a higher goal in our experiments is consistent with the idea that users dedicate less time to learning because they are "task focused." However, it may be necessary to qualify the claim that people are unwilling to take time out to learn (Carroll & Rosson, 1987). Our findings, although laboratory bound, indicate that people are willing to invest in the generation of more efficient strategies, at least within the bounds of what they can 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.

In this respect our work is consistent with previous studies of practice, including Bryan and Harter (1897, 1899), Rickard (1997), and Delaney et al. (1998). Through studying telegraphic skill, they observed plateaus in the practice curve (for receiving telegraphs), which they attributed to the later stages of the refinement of a lower-level skill (receiving letters or words) before a new level of skill (receiving words or sentences) could be mastered. They suggested that lower-level units were acquired (letters and words) prior to the deployment of strategies (*habits* in their terms) that could take advantage of higher-level units (word or sentence structures). Bryan and Harter's (1897, 1899) task differs from the copy–paste design task, as telegraphic skill requires that a very large number of chunks be formed (initially a representation for each letter must be learned followed by representations for words) before new strategies can be used. Despite the differences, however, there is a basic similarity in the finding: strategies (habits) emerge after the component skills have been acquired through practice.

Bhavnani and John (1996, 1997, 2000) have investigated the strategies generated by those who use CAD and other applications in their daily work. Bhavnani (2000) has examined a range of strategies (that use iteration, propagation, organization, and visualization) in a range of computer applications (Microsoft Word, Microsoft Excel, Adobe FrameMaker, StarOffice, MicroStation, and AutoCAD). However, this work does not empirically test the hypotheses explored in the current article. Although our experiments have focused on just one subset of the strategies required for CAD and their generality therefore needs careful interpretation, it is worth revisiting the assumption that users are slow to acquire efficient strategies without instruction. First, Experiment 1 makes it clear that some care is needed to assess the usefulness of what might appear to be more efficient methods when they are used in completion of a higher goal. Second, although our experiments did not directly test the effectiveness of instruction versus reflection in the context of higher goals, the benefits of encouraging reflection on methods and the costs (to performance and strategy generation) of higher goals are evident. Our participants generated efficient strategies within the bounds of what the higher-goal constraints allowed. These findings suggest that it may be beneficial to encourage through reflection, instead of teaching strategies explicitly, strategy generation during task performance. Further, given evidence in the problem-solving literature that there are substantial advantages for self-generation and self-explanation (Bielaczyc, Pirolli, & Brown, 1995; Chi, Bassok, Lewis, Reimann & Glaser, 1989), it may be better in the long term to ensure that users generate strategies themselves rather than explicitly teaching them strategies.

Furthermore, Bhavnani and John (1996) argued that the reason that inefficient strategies are not detected is that their use has no negative effect on the quality of the end-product. However, our results suggest that inefficient strategies not only cost in terms of the actions required to complete a task, but they also have a negative effect on end-product quality. It should therefore be possible to detect the use of inefficient strategies by examining the quality of the end-product.

It was apparent in Experiment 2 that reflecting on methods did not entirely remove the negative effect of the higher goal on performance and strategy generation. Therefore, a higher goal reduces strategy generation in some manner that is in addition to reducing the likelihood of reflection on methods. One possible explanation for this fact is that it may have been harder for participants to recognize opportunities to use efficient strategies when a higher goal was present. Further empirical investigation is required to expose the full range of constraints on strategy generation in higher-goal contexts.

Our findings suggest that the deployment of strategy-generation mechanisms may be under strategic control, with the details of the constraints imposed on the task environment determining the extent to which resources are dedicated to finding more efficient ways of using the device. In essence, the effort that a person puts into finding new strategies would be moderated by the potential gain (opportunity to use the new strategies) and by the cost (to ongoing work-related problem solving).

We have presented evidence that, in the laboratory, people can generate appropriate strategies for computer-based tasks when circumstances demand and resources allow. Our results support the view that (a) when higher goals are present, the cognitive demands of the task delay the generation of strategies that would, despite a reduction in opportunity, increase overall efficiency and that (b) strategy generation is facilitated by encouraging reflection on methods.

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New Editors Appointed, 2005–2010

The Publications and Communications Board of the American Psychological Association announces the appointment of two new editors for 6-year terms beginning in 2005:

- *Journal of Consulting and Clinical Psychology:* **Annette M. La Greca,** PhD, ABPP, Professor of Psychology and Pediatrics, Department of Psychology, P.O. Box 249229, University of Miami, Coral Gables, FL 33124-0751.
- *Developmental Psychology:* **Cynthia García Coll,** PhD, Brown University, 21 Manning Walk, Providence, RI 02912.

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- For *Journal of Consulting and Clinical Psychology,* submit via www.apa.org/journals/ccp.html.
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Manuscript submission patterns make the precise date of completion of the 2004 volumes uncertain. Current editors, Mark B. Sobell, PhD, and James L. Dannemiller, PhD, respectively, will receive and consider manuscripts through December 31, 2003. Should 2004 volumes be completed before that date, manuscripts will be redirected to the new editors for consideration in 2005 volumes.