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Problem Solving, Automaticity, & Intelligence: Evidence for Changes in Mental Representations with Practice

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PROBLEM SOLVING, AUTOMATICITY, & INTELLIGENCE:

EVIDENCE FOR CHANGES IN MENTAL REPRESENTATIONS WITH PRACTICE

By

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ABSTRACT

In research on skilled performance, emphasis has traditionally been placed on the movement from actively controlled performance to automatic performance as experience increases. Expert performance theory proposes that superior performance is marked by the acquisition of cognitive structures that operate independently of generalized abilities but are not automatic. The current study instructed a group of undergraduate students under goal-recursive strategy and control conditions with the goal of modifying the mechanisms mediating performance. Training effects were observed among difficult problems on a transfer task. Differing correlation coefficient trends between performance and general fluid abilities were found; although these coefficient differences were not found to reach traditional significance levels. Verbal reports showed individual differences in strategy use predicting performance within groups, but no main effect of group assignment on strategy use indicating that individuals did not utilize their training in the strategy trained condition. Conclusions and future directions are discussed.

INTRODUCTION

The nature of skill acquisition has been the topic of debate in psychology for several decades. In the early years of skill research, discussion was focused on skill development as a movement from the slow and error prone cognitive stage to the effortless, accurate, and quickly executed automatic stage. The seminal research outlining the automaticity view of elite performance was published by Fitts and Posner (1967) in which they argued that skilled performance is regulated by automatic processes that were not pliable or subject to active cognitive control during execution. They divided their stages of skill development into three distinct stages.

During the first “cognitive stage” task performance is slow and associated with failures of memory retrieval and errors in execution. These mistakes are generally obvious and can be corrected by referencing the correct action. As individuals gain more experience and maintain sufficient mental concentration the execution of task relevant behaviors becomes more efficient, especially for frequently encountered situations. During the second “associative stage” individuals are able to perform complex sequences of actions rapidly and with decreasing cognitive effort. After additional training and experience the individuals' performance successfully adapts to the typical situational demands and has become increasingly automated. Performers lose conscious control over discrete aspects of their behavior and are no longer able to adjust and modify these aspects of their performance (Fitts & Posner, 1967)

A contrasting view that has gained momentum as an alternate explanation for expert performance has presented convincing evidence that experts in a variety of domains avoid automaticity. They are able to accurately and flexibly modify discrete aspects of their performance throughout learning and that the apparent “effortless” task execution by experts is due to a change of the cognitive mechanisms mediating performance (Ericsson & Lehmann, 1996). These cognitive structures operate entirely independently of generalized cognitive resources and thus would appear to “free” such resources. This does not mean that the skilled performer is offline or automated, but that their performance is no longer determined by generalized capacities.

Skill Acquisition as Controlled to Automatic Processes

The traditional model put forth by Fitts and Posner (1967) has particular implications when evaluating how individuals not only improve at real world tasks such as chess, sports, or driving but also in simpler laboratory tasks. To address these questions Philip Ackerman (1987, 1990) has proposed a model based on the traditional Fitts and Posner (1967) conceptualization of skill. Ackerman places particular emphasis on the role of individual differences such as fluid abilities, perceptual speed, and psychomotor ability at each subsequent level of skill acquisition. According to his model individuals rely heavily on general fluid abilities early in the cognitive stage of skill acquisition. As development continues into the associative stage performance differences are based primarily on perceptual speed and less on fluid abilities. During the automatic stage performance is most associated with psychomotor ability. Automated performance becomes difficult to modify and few cognitive resources are allocated to task execution.

Ackerman's (1990) study examined skill development in a laboratory air traffic control (ATC) task. Between subject variability in performance significantly decreased over the course of training. High initial performers were increasing their performance to “automated” levels relatively early and lower initial performers were increasing their performance and eventually catching up to the higher performers thus reducing the variability.

Ackerman argues that the development of automatic performance is hindered by tasks that are inconsistent. Subjects are therefore more likely to automate when presented with tasks in which the parameters are very similar. According to Ackerman's predictions the relations between performance and general fluid abilities, perceptual speed, and psychomotor abilities will change as skill progresses from one stage to another.

A central tenet of this argument is that as skill increases towards automaticity there is a freeing of the cognitive resources that mediate performance during the early stages of skill acquisition. A classic example illustrating the assumptions of automaticity theory is found in the visual attention tasks conducted by Schneider and Fisk (1982). they concluded that as practice increased in a consistent visual search paradigm automaticity also increased and deficits from the introduction of a secondary task would be minimal. However if one of the visual search tasks were inconsistent then automaticity would not be achieved and the costs of introducing a second task would be high.

This theory of skill acquisition has been adequate for simple everyday tasks in which satisfactory performance is reached in a relatively short amount of time. These are activities such as everyday driving and casual sport. Individuals usually acquire a level of skill that is sufficient for them to compete at a relatively low level with their peers often with the explicit purpose of recreation. However, this viewpoint of skill acquisition falls shot in explaining elite performance by professionals in a variety of domains.

A Theory of Skill Acquisition Based on the Expert-Performance Approach

A wealth of research on exceptionally skilled individuals points to the role of complex mental representations and domain-specific memory structures as determinants of expert ability (see Ericsson & Kintsch, 1995). The identification of superior cognitive mechanisms in a variety of domains has depended primarily on the expert-performance approach (Ericsson & Smith, 1991). This approach is based on deGroot's (1946/1978) pioneering work with chess experts.

Chess ratings are based on tens, hundreds, or thousands of tournament chess matches, and these elo ratings are highly predictive of the outcome of a given chess match and is one of the most objective measurements of expertise in any domain. DeGroot found that by presenting players of different skill levels with challenging chess positions and asking them to select the best move, one could reliably predict that player's elo rating. Through this method of identifying appropriate representative tasks for a given domain, subsequent research has been able to more objectively identify not only who experts are in a domain but also the cognitive mechanisms that drive their superior performance. By isolating performance at designed, standard, and challenging points one could more scientifically evaluate the way in which experts were performing in a superior way.

Aside from his methodological breakthroughs, deGroot showed that domain specific perceptual ability was the defining feature of chess expertise. Prior to this work the popular view was that chess skill was determined primarily by superior intellectual ability. DeGroot also showed that chess experts would select better initial moves quicker than novices and were not engaging in broader searches as was previously thought. This work was extended by Chase and Simon's (1973) study demonstrating that experts' superior memory for chess positions was a result of the acquisition of complex domain-specific patterns (which they deemed chunks) over decades of experience and argued that this same memory mechanism might explain superior move selection.

Based on the research demonstrating the superior domain-specific task representations Chase and Ericsson (1982) proposed a model of skilled memory, different than the previously posited chunking theory, that addressed how individuals with normal memory capacities could develop elaborate structures for memorizing large strings of random digits. In an important experiment one individual's verbal reports showed that he was able to memorize random digits by relating short strings of numbers to running; a domain that he had extensive practice in. By manipulating the to-be-remembered digits to make it more difficult to apply them to common running situations the individual's digit span was reduced to near-normal levels. Similar findings are common in domains such as chess where experts have superior memory for real-game positions but are no better than novices at recalling randomized chess boards (deGroot, 1946/1978).

Ericsson and Kintsch (1995) elaborated on skilled memory theory by proposing a separate system called long-term working memory (LTWM) that allowed for efficient access of domain relevant information by experts. Through extensive deliberate practice skilled individuals developed complex ways of storing information crucial to exceptional performance in their field. This system was not constrained by the typical capacity limitations of non-experts. This proposed memory structure allowed for rapid and reliable access to domain-related information but it was not associated with domain-general increases. For example, digit memory experts such as the memorist Rajan have developed complex methods for encoding information into LTWM however he showed near average memory for non-numerical information such as letters (Ericsson, Delaney, Weaver, & Mahadevan, 2004).

The development of complex task representations in a specialized cognitive structure is central to the argument that the execution of tasks by experts in a domain is not marked by automatization but by the continued elaboration of domain-specific structures. More recent research has pointed to the role of complex mental representations in skilled performance (Ericsson & Charness, 1994; Ericsson, Krampe, & Tesch-Römer, 1993). This research focuses on the role of deliberate practice in developing expert performance and shows that experts are constantly modifying specific aspects of their skill to foster sustained improvement.

Furthermore, automaticity is not a characteristic of expert performance but instead can arrest continued development by taking specific aspects of performance offline from further improvements. By continually building upon a complex network of cognitive mechanisms, experts are able to identify weak aspects of their performance and modify them with the goal of improving performance. Skilled performers are able to make modifications to their skill execution that cannot be fully accounted for by automaticity theories.

If the development of skilled performance is marked by the acquisition of elaborate and complex mental representations of the task, an important question remains regarding the nature of the relationship between performance and individual differences. Namely, is a reduced relation between performance and general abilities specifically mediated by the development of automaticity or shifting cognitive mechanisms?

General Abilities and Skilled Performance

The relationship between complex task performance has been a prominent subject in the study of constructs such as fluid abilities or working memory. The traditional viewpoint holds that performance or learning relies heavily on individual differences in stable basic abilities. There is considerable evidence that these basic abilities do not predict ultimate performance or learning in complex real-world tasks. Bilalić, Mcleod, and Gobet (2006) found that within competitive chess players there was no predictive validity of individual difference variables on performance. Furthermore, Hulin, Henry, and Noon (1990) showed in a review that the predictive validity of a measure decreased as a function of the time of performance measurement suggesting that the utility of individual difference measures as predictors of performance is reduced to a level below significance over several years of experience.

Findings that the contribution of basic abilities decrease with experience would seem to confirm the claims made by automaticity theories. However, if basic abilities fail to predict performance over time identifying the specific changed cognitive mechanisms that predict performance over time is critical to a sufficient theory of how skill develops. If there are no changed mechanisms it is crucial that one identify how individuals improve the efficiency of strategies that were used in the initial contact with the task.

An extensive review by Ericsson & Lehmann (1996) outlined many of the proposed cognitive mechanisms mediating performance in a variety of domains. In the case of chess it had been observed that there are significant differences in the depth of search between novice and expert players but not between levels of skilled players. Other evidence highlights the role of acquired perceptual-motor strategies contributing to expert performance. The classic study involves the increased look-ahead strategy of expert typists. When expert typists have their look-ahead restricted by obscuring the future text their typing ability is drastically reduced (Salthouse, 1984). He inferred that superior typists owed their speed to a strategy of looking further ahead in the text. Prior to these studies it was thought that superior typists, for example, relied on generalized exceptional perceptual-motor ability.

Other domains explicate the specificity of acquired mechanisms. In memory, a study by Chase and Ericsson (1982) showed that the "basic" digit memory ability of an undergraduate volunteer could be reliably increased through training on a digit-span task. This skill displayed the flexibility and robustness of previously studied memorists. This student, who after training could reproduce over 80 random digits did not improve his memory span for consonants above six. (Ericsson et al., 1980). Investigations have demonstrated similar absence of generalizable superior performance in domains such as chess, medicine, memory, typing, and sport (see Ericsson & Lehmann, 1996).

Despite the evidence suggesting complex mental representations and other cognitive mechanisms mediating performance many popular models describe skill acquisition as a movement toward automaticity where skilled performers are using less cognitive resources to successfully execute tasks in their domain (Ackerman, 1987, 1990). Studies specifically assessing the role of changed cognitive mechanisms in declining correlations between task performance and general ability measures are scarce. One issue with such designs is the retrospective nature of assessing expert performance in real-world tasks. It is difficult to assess between subject differences in the relations of interest in individuals allowed to take a path toward automatic performance and those allowed to develop complex and flexible understanding of a domain.

Measuring Mediating Cognitive Mechanisms With The Tower of Hanoi

The Tower of Hanoi (TOH) has a long history in cognitive psychology and is an ideal candidate for a laboratory problem solving task. It has been used by researchers for decades (Kotovsky, Hayes, & Simon, 1985; Simon, 1975; Welsh, 1991). The TOH is a transfer problem in which differing numbers of disks are moved across three pegs to a "goal state" under three conditions (a) disks may only be moved one at a time (b) no larger disk may rest on a smaller disk and (c) disks must always rest on a peg except for when being moved. This problem provides a particularly clear problem space. The recursive nature of the problem makes the correct moves counter-intuitive, requiring solvers to develop more elaborate strategies for effectively solving the problem.

A seminal paper published by Carpenter, Just, and Shell (1990), which was predominately concerned with cognitive processing in the Raven Advanced Progressive Matrices test presented a relation between TOH performance and the Raven that was striking ($r(43) = .77$). The authors hypothesized that this relation was a function of a shared mechanism for both the TOH and the Raven, namely working memory capacity (WMC). They claimed that by instructing participants in a strategy requiring them to maintain increasing numbers of subgoals in WM individual differences in TOH performance would be highly related to Raven performance which also taxes WMC.

The pioneering research on the TOH focused on interventions that could improve problem solving. Gagne and Smith (1962) examined the effect of requiring participants to explain their reasons for each action. They found that being required to explain each move improved their performance on three to five disk problems as well as transfer to a six-disk problem compared to a control group. Several subsequent studies examined the effects of verbalization on this task and found that the requirement of explaining one's actions was the crucial aspect for improving performance, whereas merely "thinking aloud" or verbalizing one's thoughts did not reliably influence the number of moves in the solution (for a review see Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995; Ericsson & Simon, 1993). Most of the subsequent research was focused on general characteristics of problem solving during the TOH (Karat, 1982; Kotovsky, Hayes, & Simon, 1985).

The TOH has some advantages over real-world and other cognitive tasks for the study of strategy acquisition. The TOH was the task of choice for problem solving researchers studying artificial intelligence and models of human cognition (Anderson & Douglass, 2001; Anzai &

Simon, 1979; Kotovsky et al., 1985; Simon, 1975). Subsequently there was heavy emphasis on uncovering cognitive strategies that were predictive of performance. The TOH task exists within a well-defined problem space and several strategies may be developed in order to obtain an optimal solution to the problem although all are not as efficient as efficient or robust.

A classic study on TOH strategy acquisition (Anzai & Simon, 1979) focused on one subject's strategy evolution through several trials of the TOH five-disk problem. This highly motivated subject showed a clear progression from a selective search strategy to a goal-recursive strategy over the course of one study session. The subject was instructed to work through the five-disk problem until solved. The participant was allowed to start over when she felt that she was on the wrong solution path and was asked to give reasons for making specific moves.

Traditional studies (Anzai & Simon, 1979; Simon, 1975) have described the role of generalization of principles in developing new strategies. This traditional view of problem solving on this task lends itself to computational modeling that can mimic the rule production of human participants when in reaches impasses in which the current production system is no longer optimal. Vanlehn's (1991) reanalysis of the Anzai and Simon protocols argue that rule acquisition events are not always the result of impasses but rather that they occur through gradual generalization and miniature experiments that are not necessarily designed to increase efficiency but to understand the problem structure.

Cicerello, Cuneo, & Brennan (1995) contrasted the problem solving characteristics of very good solvers compared to less good solvers. They concluded that high performers were more likely to devote a longer time at the key decision points and recognizing them as important for planning for the next subgoal and the correct completion of the problem. More recent studies have examined the effect of task manipulation on strategy generation. A study by Welsh and Huizinga (2005) evaluated performance on sixty trials of the TOH 4-disk problems. By varying the beginning and goal states of the problems they administered the sixty items in either a blocked (sequential) or randomized order. They found that manipulating blocked versus randomized task formats had no effect on either performance or strategy generation. However, individual differences in strategy generation did significantly predict performance on their TOH-revised test.

Verbal report (think-aloud) data has been used to evaluate individual's problem solving principle use during execution of the TOH. Simon (1975) outlined the strategies that could be used to solve the TOH. The first and most effective method he called the goal-recursive strategy. This strategy involves setting up increasing numbers of sub-goals in order to work recursively to the first move from the current problem state. For example, in a four disk problem (see appendix) the first sub-goal would be to move the top three disks to the middle peg, the second sub-goal would be to move the top two disks to the third peg and so the final sub-goal would be to move the top disk to the second peg and thus that move would be made. By repeating this process one could solve a TOH problem with any number of disks from any problem state.

The second strategy outlined by Simon (1975) is the perceptual strategy. Although divided into regular and sophisticated varieties the current study focuses on the general characteristics of the perceptual strategy. This strategy involves identifying the target situation; in the four disk problem this would be to move the bottom largest disk to final peg. The solver then wants to move any smaller disks blocking the movement of the larger disk such that they do not rest on the target peg. However, as Simon points out the simple execution of this strategy could sometimes lead to recurring loops and thus this strategy is sub-optimal.

The third strategy was termed the move-pattern strategy. This simply involves mentally “moving” the discs such that each step in the process must be stored. This strategy is the least effective of the three and is at high risk for memory failures and mistakes due to the amount of information to be stored and managed; this is especially true for problems with more than four disks.

The Tower of Hanoi and General Abilities

Since researchers first began elucidating their ideas about the nature of human abilities there has been particular interest in the predictive value of general ability measures such as intelligence or WMC. There has been an emphasis on the role of fluid abilities in complex problem solving behavior due to an assumed shared reliance on generalized executive control. Perhaps the most widespread and popular measure of fluid abilities is a pattern-completion task, Raven's Advanced Progressive Matrices. Raven's scale has been claimed as a valid measure of fluid abilities and executive function (Unsworth & Engle, 2004) and working memory capacity (Carpenter et al., 1990; Conway, Cowan, Bunting, Therriault, & Minkoff, 1999).

Many studies have looked at the relationship between matrix reasoning tasks such as the Raven and performance on the TOH. As discussed earlier Carpenter et al. (1990) reported an astonishing .77 correlation between Raven and TOH performance. Other accounts have found that the correlation between a modified TOH-R and Weschler Matrix Reasoning Scale were low-to-moderately correlated ($r = .25$) (Emick & Welsh, 2005). In a study of the TOH and the Tower of London tasks Zook, Davalos, DeLosh, and Davis (2004) found a significant relation ($r = .41$) between the Weschler Matrix Reasoning Scale and TOH performance. A dissertation by Fleck (2005) found no relationship between the full-scale Raven's Matrices Test and performance on a single four-disk TOH problem. These correlation coefficients are considerably lower than the one observed by Carpenter et al. (1990); although not significantly different in some cases.

Summary and Predictions

The current study seeks to reconcile the findings of previous studies in the context of a shifting cognitive mechanisms approach. The two competing explanations of skill development performance provide very different predictions regarding expert performance and individuals' performance relation to general cognitive abilities over time. The first of these views skill development as a continued refinement and execution of acquired procedures for a particular domain. For example, participants improving speed of execution on a laboratory task over many hours of practice. This improved efficiency is the result of the composition of intermediate steps into a single processing step (Anderson, 1982). That is, discrete aspects of performance are integrated across training causing cognitive resources to be freed and fewer intermediate steps need to be processed in WM. This approach naturally places emphasis on the role of various cognitive resources such as working memory capacity (Carpenter et al., 1990), fluid abilities, perceptual speed, and psychomotor ability (Ackerman, 1987) in determining performance at different levels of skill acquisition.

The second account proposes that highly skilled performance in challenging task environments is never fully automated. Additionally, complex cognitive mechanisms are acquired, constructed, and accessed without the need for mediation by basic cognitive abilities. This approach allows for quick and accurate execution of domain related tasks as well generalizability when approaching unfamiliar — yet domain related situations. This view also contrasts with the automaticity model because it holds that discrete aspects of performance are reorganized in such a way that they can be quickly accessed for use in domain-relevant tasks and changed if necessary and that they are not aggregated or integrated into larger procedures as theories of skill based on automaticity proposes (Anderson, 1982). The classic example in memory research regards memorists' ability to recall digits in several formats and very rapidly encode and retrieve digits from memory. Additionally, chess masters very rarely encounter middle-game situations that they have seen before but they are still able to select consistently superior moves.

The main approach in this study is to assess transfer with a controlled but complex laboratory problem solving task. Training conditions that can foster a deep understanding of the TOH problem structure will allow for more robust transfer to domain-related but novel problem states relative to a control training condition. Individuals that have been trained with the goal-recursive strategy are predicted to perform better than non-instructed groups on related transfer tasks. More specifically, transfer differences between groups are predicted to be largest when the transfer task is differs most from the trained task. For example, when trained along a peg A to peg C solution path transfer to a peg C to peg A problem would be robust because the solver can solve it as a mirror image of the original problem. When the problem involves moving the discs from Peg B to Peg C there does not exist such a simple mapping to the trained solution of the A-C problem. The sequentially trained group is predict to outperform the other groups on the C-A transfer task because of the familiarity with the specific procedure for solving the A-C problem compared with the groups that receive the randomized training.

This study also seeks to examine the role of fluid general abilities across different levels of task understanding. Specifically I predict that general abilities (Raven) will have a low relationship with performance in a group instructed in the G-R strategy. Furthermore, this relationship is predicted to be significantly higher in the groups not given strategy training, leading to a significant interaction between Raven’s prediction of performance in the different groups.

METHODS

Participants

Seventy-eight participants were drawn from the introductory psychology participant pool at Florida State University and participated for course credit. Three subjects were eliminated from analysis due to technical difficulties resulting in an total of 75 subjects.

Materials and Design

The short version of Raven's Advanced Progressive Matrices was used. The test consists of 12 items drawn from the original 36 item version arranged by increasing difficulty; this test has been shown to be a reliable predictor of full-scale Raven performance (Arthur, Tubre, Paul, & Sanchez-Ku, 1999). The test was presented on a computer monitor and participants were required to press a number on a keyboard corresponding to their answer choice. Each participant was given 20 minutes to complete the task. Their score was calculated as the total number of correct responses out of a possible twelve.

The training task contained 30 disk states drawn from various minimal solution paths of the four disk TOH task. The required goal states vary between peg B and peg C: the “start position” was peg A. For each presented position participants were required to indicate on the keyboard what their next move toward the solution would be by pressing a colored key corresponding to the color of the disk and a lettered key corresponding to the peg (A, B, or C) to which they wished to move it. All participants were provided with feedback on the accuracy of their move choice, participants in the goal-recursive (G-R) training group were required to answer eight problems correctly before continuing to the next tasks. All other groups received a number of training trials yoked to the amount needed by the G-R group in a rotating fashion to ensure that each group receives equal mean amounts of exposure to the training. Under the G-R training condition subjects were required to work through the G-R strategy when choosing an incorrect move.

The G-R and second group (henceforth referred to as the randomized training group) received the move states in a quasi randomized fashion. The 30 state problem space was divided into four groups consisting of the first eight states from each path (A-C and A-B) and the last seven states from each path. Problems were randomized within these divisions and presented in a sequenced fashion between divisions to ensure that participants were not given a disproportionate number of states close to the solution. Group three (henceforth referred to as the sequentially trained group) received the move states in a sequential fashion from A-C followed by the A-B move states.

The first transfer task is a traditional TOH task in which participants manipulated two four-disk problems with the goal of moving the stack of disks from peg C to peg A and peg B to peg C. The task was “constrained”. Participants' moves were restricted to the minimal solution path. When an individual attempts to make a non-optimal move the computer program sounded a tone and required them to choose a different move. Participants' score was the total number of incorrect move attempts.

The second transfer task contained problem states from the five and six disk problem spaces in which participants indicated the best next move toward the goal state with no feedback. Half of the presented problems were drawn from the minimal solution paths from A-C for each problem and half were drawn from non-minimal problem states. Problems in each of these divisions were matched for distance from the goal state to control for the number of intermediate steps between the problem state and solutions. Additionally, these problems were timed. Time was allotted based on the number of disks in the problem with more time allowed as the number of disks increased.

Procedure

Each session began with participants receiving instructions for giving concurrent and retrospective verbal reports. Following the verbal report instructions the remainder of the tasks were carried out with the participant thinking aloud. The short Raven was administered followed by a basic rules video for the TOH task. Following task instructions, participants in the goal-recursive experimental group were given strategy instructions adapted from Simon's (1975) informal description of the G-R strategy. Additionally, this group received G-R coaching when they gave an incorrect answer during the training task. This coaching consists of asking key questions related to the execution of a G-R strategy such as: What is the largest disk that needs to be moved? Where should you move it? What disks are obstructing that move? The other two experimental groups worked though the training task with no strategy instruction. All participants were then required to work through both TOH transfer tasks.

RESULTS

The first hypothesis concerns training effects on the two TOH transfer tasks. The general prediction was that the G-R instructed group would be superior on the relatively far transfer problems while the sequentially trained group would perform significantly better on the near transfer problems. More specifically, the G-R group was predicted to perform better on the second transfer task on which the included items are five and six disk problem states that would differ more from the four disk training situations. The sequentially trained group will perform better in comparison to the other groups on the first transfer task which is more similar to the training conditions.

The efficacy of the strategy instruction was evaluated by comparing the G-R group and the randomized training group on the average accuracy on the training problems. The sequentially trained group was excluded because their training task format was not directly comparable to the other groups' tasks. Transfer of training to TOH transfer tasks depends on the extent to which G-R instruction influenced performance on the training task itself. Analysis revealed that the G-R group's mean performance on the training task was significantly better than the randomized training group, $F(1, 48) = 4.16$, $p < .05$. Training accuracy was also significantly related to Raven score, $r(48) = .42$, $p < .005$; transfer task one performance, $r(48) = -.54$, $p < .001$; and transfer task two performance, $r(48) = .48$, $p < .005$. This suggests that early success on the training task is highly related to success on the transfer tasks.

The score on the first transfer task was calculated by summing the number of incorrect move attempts. The resulting skewed scores were added to a constant and log-transformed to provide a more normal distribution for later analyses. Table 1 shows descriptive statistics for the first transfer task. Contrary to hypotheses a one-way ANOVA revealed no significant group differences on performance on the first transfer task, $F(2, 72) = 1.52$, $p = .227$.

For the second transfer task each item was scored as either correct or incorrect based on whether the selected move was on the optimal path toward the solution. These scores were summed to form an aggregate variable used in the analyses of the second transfer task. The descriptive statistics for the second transfer task are shown in Table 1. An examination of the mean group differences failed to reach traditional significance levels, $F(2, 72) = 2.50$, $p = .089$.

For follow-up analyses the items on the second transfer task were divided into easy and difficult categories. Although a median split of the items fell at 54 percent accuracy the difficult problems were defined as those with mean accuracies under 50 percent. Fifty percent was the percentage at which there would be an equal number of easy and difficult problems . Each of these groups were subsequently summed to form new aggregate variables. A one-way ANOVA revealed a significant group training effect on performance on the difficult problems, $F(2, 72) = 4.25$, $p < .05$, but not the easy problems. Fisher's least significant difference comparisons showed that the G-R group was significantly better than the sequentially trained group on the difficult problems $p < .01$ but the G-R group and randomly trained group were not significantly different from each other. The randomly trained group was not significantly different from the sequentially trained group.

Table 1

Descriptive Statistics for TOH Transfer Tasks Separated by Group

Group Assignment	N	Mean	Std Dev	Min	Max
		Transfer Task 1			
G-R	25	2.56	2.65	0	10
Random	25	3.20	2.66	0	10
Sequential	25	1.92	1.63	0	6
		Transfer Task 2			
G-R	25	16.68	4.45	6	23
Random	25	15.40	4.44	4	24
Sequential	25	13.92	4.2	6	23

Note. Transfer task one values are presented for raw scores before log transformation performed prior to analyses.

The second general prediction concerned the relationship between performance on the two TOH transfer tasks and Raven scores between groups. Specifically I hypothesized that there would be a significant group interaction where the G-R group would have a significantly lower relation between transfer task performance and Raven compared with the other groups. Specifically the slope of the Raven by transfer task performance regression line in the G-R group would be positive but significantly lower than the slope of the line in the other two groups.

Pearson correlations were calculated between Raven scores and TOH transfer tasks one and two and are displayed in Table 3. Dummy variables were created to compare the Raven by performance relation between each group. Each variable was entered into a linear regression model with each main effects as well as terms for the interactions between group and Raven predicting performance separately for each of two TOH transfer tasks. The analyses revealed no significant interaction between group and Raven indicating that the slopes of the Raven by performance regression lines for the G-R trained group was not significantly different, from the randomly trained group, $\beta = .152$, $t(69) = .882$, $p > .05$, or the sequentially trained group, $\beta = .117$, $t(69) = .854$, $p > .05$. The regression analysis was performed again using the previously formed aggregate variable for the difficult problems for transfer task two. There was a main effect of sequentially trained group assignment but no significant interaction between Raven and group assignment.

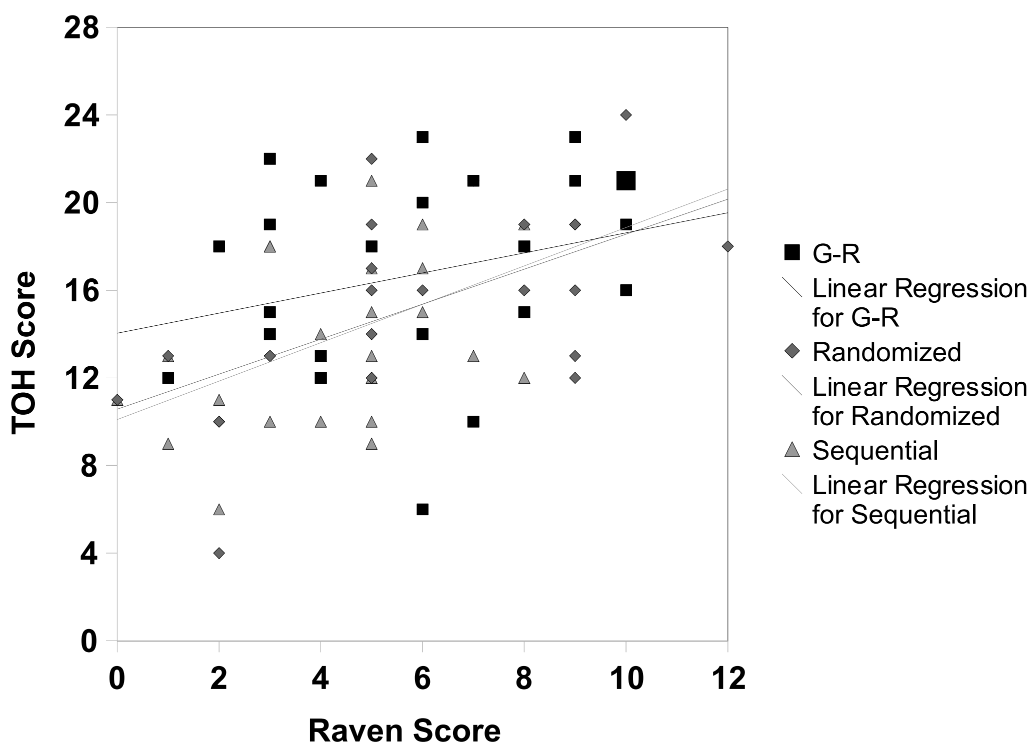

Figure 1: Correlation between Raven performance and TOH transfer task two performance separated by group

Verbal Report Data

Verbal reports were coded for strategy use and analyzed to test the hypothesis that there were individual differences in strategy use within groups that may have contributed to the lack of a generalized training effect on the second transfer task specifically. The think-aloud verbalizations for each item on the TOH transfer task two were coded for one of six possible strategies based on Simon's (1975) seminal work on the TOH task. These categories were: goal-recursive, perceptual, move-pattern, mixed, unclear, and no verbalization. The prevalence of mixed and no-verbalization items was negligible and will not be included in subsequent analyses. See table 2 for examples of verbalizations from each category. Each participant was given a score for each of the six categories.

Table 2

Example strategy verbalizations from TOH transfer task two

Category	Verbalization
Goal-Recursive	…so you're trying to get yellow to the third one so you had to get the rest to the middle so blue is over there so you have to move you have to move the smallest to the non so the aim is there so the none one would be the middle so you'd move blue to yellow, then green to blue, no you move green to blue no blue to blue you'd move blue to blue for the first move so that one to that one...
	...so the non-target peg is the middle one. Yellow and blue are already on the target peg. so the first thing you do is put the OK so there's three goals to the target the non-target, instead of going to the target. So you go, OK, blue to the middle, green there, blue on top of that, red there, blue back, green there, blue there, wait, no, we need to get red there, oh. So blue to the target, blue to target, green, OK, blue to target, so first I have...
Perceptual	...ok so you have the yellow needs to...gold to the target position then you have the dark blue and brown sitting on top so they need to get out of the way so move the blue to the target position then put the brown one on B then then the blue on the target so dark blue to C...
	...the biggest one not in the target position is the red and you need move it to the target position and you need to get all those off it so you need to move the p to the target position so then you can move the blue over there and that on top...
Move-Pattern	...I would move the blue on to the second peg so I can move green to the first then the dark blue on the first then I can move that peg on that one...
	...I would move the blue to the second then green to the third no I'd move blue to the third green to the second; no I'd move blue to the second then green to the third...blue to the second...
Unclear	...I would the red to the first...
	...I would move the blue to the first...

Verbal report analysis was performed on 74 of the 75 subjects in the study. One was omitted due to technical difficulties relating to the voice recording. To assess the efficacy of the various strategies all groups were analyzed together and zero-order correlations were calculated between each strategy and performance on transfer task two. All variables were log transformed to correct for a right-skewed distribution since the modal score for a given strategy was zero. Use of the goal-recursive strategy was positively related to transfer task performance, $r\ (72) = .39$, $p < .005$ and the unclear strategy was negatively related to performance, $r\ (72) = -.48$, $p < .001$. Use of the perceptual strategy or the move-pattern was not significantly related to performance. A oneway ANOVA revealed a significant difference of G-R strategy use between groups , $F\ (2, 71) = 6.67$, $p < .005$, a Fisher LSD post-hoc test showed that subjects in the G-R group used the G-R strategy significantly more often the those in the sequentially trained group but not more than those in the randomly trained group. There was also a a significant main effect of unclear strategy use, $F(2,71) = 4.84$, $p < .05$ with participants in the sequential group using the strategy significantly more often than those in the G-R group but not more than those in the randomized training group. Individual subject's score for a specific strategy was not found to have a significant ($p<.05$) relation with Raven performance for the G-R, $r\ (72) = .11$, perceptual, $r\ (72) = -\ .03$), move pattern, $r\ (72) = .19$), and unclear strategies $r\ (72) = -.03$.

Additional Analyses

One potential issue that would limit the findings regarding the relation between performance and Raven is the stability of acquired strategies within tasks. Correlation coefficients are limited by the intra-task reliability of the tasks being correlated and therefore potential differences in relationships could be due to differences in the variability of items within a task between groups. Therefore, Cronbach's alpha coefficients were estimated across all groups ($\alpha = .74$) and were not found to be significantly different between each of the three groups. It is unlikely that reliability issues contributed to the effects observed in the study.

Correlation coefficients between the two TOH transfer tasks were very high in the two groups given the randomized training, $r\ (23) = -.61$, $p < .01$ and $r\ (23) = -.63$, $p < .01$ and were much lower in the sequentially trained group, $r\ (23) = -.27$. However, these coefficients are not significantly different from one another (see table 3).

Table 3

Intercorrelations Between Raven APM and TOH Transfer Tasks Separated by Group

	1	2	3
	G-R (n = 25)		
1. Raven	--	- .16	.27
2. Transfer Task 1		--	- .61**
3. Transfer Task 2			--
	Random (n = 25)		
1. Raven	--	-.41*	.61**
2. Transfer Task 1		--	-.63**
3. Transfer Task 2			--
	Sequential (n = 25)		
1. Raven	--	-0.17	.44*
2. Transfer Task 1		--	-0.27
3. Transfer Task 2			--

Note. Transfer task 1 = number of incorrect move attempts

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

Completion time for each of the tasks were entered and analyzed. There was a significant group effect on completion time for the second transfer task with the sequentially trained group having a significantly lower mean completion time compared with the randomly trained groups $F(2, 72) = 7.34$, $p < .01$. Additionally, Raven completion time significantly predicted performance on transfer task one above and beyond Raven performance $\beta = -.34$, $t(72) = -2.79$, $p < .01$ and similarly on transfer task two $\beta = .23$, $t(72) = 2.05$, $p < .05$.

DISCUSSION

Summary and Implications

The surprising finding was that strategy instruction did not reliably cause performance differences between groups. The relatively small effect that instruction had on training accuracy suggests that the likelihood of transfer to a different task is low. If one were to observe huge differences between groups on the training task itself than it would be more appropriate to expect sufficient transfer to yield a reliable result. This raises important questions regarding the efficacy of training on domain-similar but problem-different tasks. Namely, under what conditions would strategy instruction be effective enough to transfer to unfamiliar problem situations?

Extending the amount of training would be one option. When one compares experimental and control groups given similar amounts of experience with the task, it is unclear that the increased training time would catalyze the expression of group differences on transfer. Some research suggests that individuals who receive structural instruction on problem solving tasks show delayed performance increases during an interval in which they assimilate their instruction into relevant problem scenarios (Hilgard, Irvine, & Whipple, 1953).

When training scenarios are limited, as in the current study, it may be difficult for naïve learners to generalize learned principles to different types of problems. For example, training on only problems with an even number of disks may lead participants to select strategies that are particularly effective for even number disk problems but would not generate to problems or situations in which an odd number of disks need to be used. The learning principles acquired in training need to not only increase performance on the training itself to reach appropriate criterion, but they also need to be applicable to unfamiliar problems. The production of problem-specific strategies may be encouraged by limited variety in training problems. Further analyses could examine those individuals that received more training trials and contrast them with those that received less trials to evaluate transfer differences.

In addition to the limited variability in training scenarios, the requirement of a specific performance level as the sole criterion on these limited training problem states may be problematic. When strictly requiring a minimum performance level to proceed instead of more stringent understanding criteria, participants are able to advance using strategies that are sub-optimal. This is even more likely with four disk problems that can be readily solved using such strategies as the perceptual strategy or even the move-pattern strategy. Measuring learning during the training task could assess whether individuals in the G-R group are exhibiting different patterns than participants in the other groups. No differences would suggest that participants are following a "natural" progression of learning and are not adjusting their approach due to any experimental manipulation.

Additional verbal report analyses may reveal strategy generation during the training task and give direct evidence that individuals were not utilizing the G-R training but were nevertheless able to meet performance criterion. In future studies, criteria could be designed to not only meet a given performance goal but also to actively use the strategy that is being experimentally administered.

Transfer of training to related problems has been shown to be difficult in other studies as well. Particularly studies with an emphasis on transferring a specific strategy to additional problems sharing the same structure. Hilgard, Edgren, and Irvine (1954) examined high-school senior's performance on Katona's Card Trick problem. Using different strategy instruction they concluded that transfer to more difficult problems was limited regardless of strategy instruction. This replicated and extended a similar finding showing that groups with training for understanding and memorization performed equally on followup evaluations (Hilgard et al., 1953).

While the current study revealed no group differences in performance there were individual differences in strategy use that were significantly related to performance. As expected, those individuals that used the goal-recursive strategy had increased performance on transfer task two. Those individuals who's strategy was unclear (usually when they only mentioned one move) were at a disadvantage on the TOH transfer task. Additionally, while these two strategies were related to group assignment, their weight on the overall performance effect was not enough to drive between-group differences in performance on transfer task two. With think-aloud data it is possible to evaluate those individual differences that exist independent of group manipulations to compare the efficacy of various applied strategies and make further contrasts in future analyses.

The second important question regards the relation between performance and general ability. The current study showed a trending Raven by performance interaction between groups. While caution must be used when interpreting the difference in these relationships between groups it becomes an important question if these correlation differences were generalizable to the population. More specifically, what would be an appropriate hypothesis regarding these differences. It would be difficult for automaticity theories to explain the difference in correlations between the groups given that they received the same training regimen (the G-R and randomized group) and matched amounts of experience.

Expert performance theory would argue that the differences in correlations can be explained by differences in the cognitive mechanisms mediating performance. Namely that the mechanisms mediating performance in groups with a reduced correlation are different than those mediating performance on Raven and in groups with high correlations those mechanisms are similar. These claims can be evaluated by examining think-aloud data. One would hypothesize that the verbalized processes occurring would be quite different between groups utilizing different cognitive processes. Future analyses could isolate those that used a particular strategy and contrast their performance by Raven correlation with those using a different strategy.

When examining the findings in the current study against those in prior studies there is one substantial difference. Primarily, the difference between the correlation in the G-R trained group is significantly lower than the correlation reported in Carpenter et al. (1990). This indicates that there are some discrepancies between the characteristics of the processes occurring in the two studies. Since Carpenter et al. (1990) did not assess any process data and assumed that, because of the goal-recursive training, individuals were actually using a goal-recursive strategy but that assumption may not have been true for the duration of training. It may be that the individuals in the Carpenter et al. (1990) study were utilizing cognitive mechanisms that were more similar to the randomized and sequential training groups' than the G-R training group's.

In contrast there was no significant differences between the correlations found in the non-instructed groups and correlations reported in prior studies in which participants were not instructed in a strategy (Fleck, 2004, Zook et al., 2004; Emick & Welsh, 2005). These results remain to be fully reconciled but the variability in correlation coefficients suggest that there are wide differences in the way that individuals, trained groups, and different samples are approaching the TOH task.

The current study shows the difficulty in training a skill, especially for deep understanding of underlying task structure. While strategy instruction designed to give participants a unique advantage over other groups would seem to be an obvious way to improve performance on related transfer tasks it has proven to involve much more complex processes. Despite improved performance on the training task, the advantage of the G-R instructed group did not transfer to even closely related problems. This has potential implications for how strategy instruction is approached.

There are several points to be made regarding the use of strategies on the TOH transfer task. First, it is clear that there is variability in strategy use within the individual. The same participant does not have perfect homogeneity of strategy use even within the same task. This could be a function of an instability in the learning process or external factors such as the structure or surface features of certain problems. Future analyses could identify items that are similar and compare verbalized strategies to better understand why individuals switch strategies or if changing strategies are a function of ongoing hypothesis testing. Second, the use of a specific strategy was not related to general abilities. Some would suggest that those with high fluid abilities would be better able to understand or utilize an instructed strategy stressing deep understanding but this was not the case. Third, in order to increase transfer in future studies, training must be designed with strategy understanding must be included as a learning criterion with performance as a secondary requirement.

Future Directions

Future studies should be designed to more fully take advantage of training opportunities that foster deep understanding of the problem structure. Between-subject comparisons on transfer tasks are difficult because ideally a manipulated group would have the same amount of experience as a non-instructed control group, to make a convincing argument that any discovered performance differences are a function of the strategy instruction and not increased experience. The requirement that these groups be held to equal amounts of training experience works against group differences if one assumes that those in a control condition will elaborate on their initial strategies over time. Therefore, future studies should take caution to evaluate learned principles and strategy use before, during, and after training before assessment of transfer performance. Further studies should also design training that includes a wider variety of problem states.

Limiting the variability in items on the training task fosters the reliance on strategies that are not optimal for transfer performance.

The assessment of transfer performance in challenging situations is also critical in shedding light on the differences between individuals or groups that are utilizing different strategies to solve a particular problem. If a problem is not challenging enough, individuals with less elaborate strategies will be able to solve them at a level comparable to those individuals using more generalizable strategies.

In conclusion, the current study fell short in its attempt to identify how performance changes on a representative transfer task as a function of strategy instruction, and there was no significant interaction of Raven and performance between groups. However, there were several interesting findings that should be explored in future studies. The identification of superior training conditions as well as challenging representative transfer tasks should be prioritized in any future study in order to more effectively evaluate how skill develops under optimal conditions and how the eventual skill relates to general abilities.

APPENDIX A

IRB APPROVAL DOCUMENTS

INFORMED CONSENT FORM

Date:__________________

I freely and voluntarily consent to be a participant in the research project entitled *"The Structure of Fluid Intelligence: What the high correlations between performance on Raven's Matrices and tests of problem solving can tell us about what g really measures."* The principal investigators will be Dr. K.A. Ericsson and Tyler J. Towne.

I understand that I will be given tests measuring different cognitive abilities. These tasks include a test of the way one works with shapes and patterns, and two computer tasks assessing problem solving ability. During these tasks talk/think aloud information (e.g. speaking my thoughts aloud while I perform) will be audio/video recorded for later protocol analysis. A post session retrospective of my thoughts during my practice performance may also be recorded for later analysis. The total time needed for this experiment should not exceed the time which is consistent with the course credit I will be earning. I also understand that the current research has the potential to help researchers better understand the relationship between problem solving and intelligence.

I understand that the records of this research which refer to my cognitive strategies will be given a code so that no one except the investigators and their designated assistants will have access to the data, and that no identifiable data, including handwritten information that I have supplied, will be used for publication. In addition, the records of this research, which refer to my performance, will be kept confidential to the extent allowed by law. I understand that any video or audio tapes used in this project will be retained at the FSU Department of Psychology, and that the tapes will be erased or destroyed within ten years (no later than December 31, 2017). I understand that I will be receiving course credit (introductory psychology) for participation in the current study.

This consent may be withdrawn at any time without consequence. I have been given the right to ask and have answered any inquiry concerning the foregoing. Questions, if any, have been answered to my satisfaction. I understand that I may contact Dr. K Anders Ericsson, Department of Psychology, Florida State University, Tallahassee, FL 32306, phone: (850) 644-9860, or Tyler Towne, phone: (850) 559-2452, for answers to pertinent questions about this research. The primary risk involved in this study is boredom, but should any discomfort or distress arise, participation can stop immediately without penalty and you may speak with the principal investigators (Tyler J. Towne or Dr. K. Anders Ericsson) regarding any issues with the protocol. I have read and I understand the foregoing.

If I have questions about my rights as a subject/participant in this research, or if I feel that I have been placed at risk, I can contact the Chair of the Human Subjects Committee, Institutional Review Board, through the Office of the Vice President for Research at (850) 644-8633.

FSU Human Subjects Committee approved on 6/18/2009. Void after 6/17/2010. HSC#: 2009.2874

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673 · FAX (850) 644-4392

RE-APPROVAL MEMORANDUM

Date: 6/18/2009

To: Tyler Towne [towne@psy.fsu.edu]

Address: 1107 W. Call Street
Dept.: PSYCHOLOGY DEPARTMENT

From: Thomas L. Jacobson, Chair

Re: Re-approval of Use of Human subjects in Research
The Structure of Fluid Intelligence: What the high correlations between performance on Raven's Matrices and tests of problem solving can tell us about what g really measures

Your request to continue the research project listed above involving human subjects has been approved by the Human Subjects Committee. If your project has not been completed by 6/17/2010, you are must request renewed approval by the Committee.

If you submitted a proposed consent form with your renewal request, the approved stamped consent form is attached to this re-approval notice. Only the stamped version of the consent form may be used in recruiting of research subjects. You are reminded that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report in writing, any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor are reminded of their responsibility for being informed concerning research projects involving human subjects in their department. They are advised to review the protocols as often as necessary to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

Cc: K Ericsson, Advisor [ericsson@psy.fsu.edu]
HSC No. 2009.2874

APPENDIX B

SAMPLE TOH PROBLEM

APPENDIX C

EXAMPLE TOH TRANSFER TASK TWO TRANSCRIPTION

1. Okay, The first thing you need to do is to move… you want to move the yellow to the third column
so, we want to first move the red one out of the way
but I think the best move would be just to move the blue one over to yeah. The blue to move to A. Blue A.

Retrospective Report: Blue A. I was just trying to like look ahead and figure out if I did this then this one what would happen next and if I was going to be able to move the yellow box over to the third one and what would be like, the easiest way to do that.

2. For this one we need to move the blue and the green one off, and the red.
We need to move all of them to the third column.
So the easiest way to do that would first move the blue to the first or the third column
and then the green and
then stack them and
then put the red one over so we can move the yellow one.
So I'm going to say the blue one goes to A. Blue A.

Retrospective Report: Um, the same thing I was just trying to look ahead and think fast. Oh, I was thinking if the blue one goes to the first column and then the green what would happen? And then I thought about the green going to the second one and I thought green in the second one, and then the red and then stacking them also. I was just trying to see like, which one was best.

3. Okay, for this one all of them also, the same thing, need to be stacked to the third row.
So we'd make way for the yellow one to move first.
So we needed to get the blue and the green off of it.
So the easiest thing to do I think would just move the blue over to the, the third one and
then the green the second and
then move the blue back so I'm going to say blue C.

Retrospective Report: Um, I figured out what needed to be done with the, the final thing needed to look like and looked at the yellow one moving to the third row and then tried to figure out where the first blue block should go, either the second or third column and which would be the easiest one.

4. This one, the first yellow column, the first yellow box is already in the right spot
so we need to move the rest of the blocks off of the blue block to move.
So gee, first thing I'd say is to move the blue block obviously, to either the first or third so if it, it would have to.
If it went to the third and
the green went to the first
I could move the blue back and
then the red and then I think I'd be stuck.
So I'm going to move the blue block to the first one.

Retrospective Report: I just… tried to think really fast and figure out where the blue block, was the only one that needed to move somewhere because the first… Oh, okay. Trying to figure out the blue block needed to go to the first or third column and I figured it out from there.

5. Okay in this one the yellow block is in the right spot
so I want to move the blue block first so I can make room for the right blocks.

So I want to move the blue one out of the way
so I'm going to move that to the first column.

Retrospective Report: Um, I wanted to move the blue block out of the way and looked to see which column would be the best one for it. And I picked the first one.

6. In this one, two of the blocks are in the right spot
so we just need to move the red one over
so we needed to move the blue and the green one out of the way.
So the blue one needs to go on the third one first, and
then the green to the second.
So blue to C.

Retrospective Report: I picked blue to C because I knew that I needed to get that block out of the way first. And then I looked ahead to make sure I was right, so I picked blue and C.

7. And then for this one three of the blocks are in the right place
so all I need to do is just move the blue one to the first column
so the green one can move um to the third. And be in the right place.
So blue A.

Retrospective Report: Blue A because that um, left the green one free so it could move to the stack and be in the right spot.

8. This one I need to move two blocks out of the way that are out of order
so the first block to go would be blue.
So I would either move the blue in the second or third and
I'm going to pick the third because then I can stack it later on the green one in the second column
and the red one can move over to the first.
So I'm going to pick blue, C.

Retrospective Report: Blue c. I needed to move the blue one out of the way because it was in the wrong order so I moved it to the third column to leave room for the one underneath to move also, so they could stack. That's what I remember.

9. And then all of them are out of order in this one the first block that needs to go down is the yellow in the third column
but to even move that first we have to move the blue
so I need to move the blue on the third column. I believe.
No, I'm going to no. I'm going to move it to the second column.
Because if not then the red one's not going to be able to go anywhere.
So I picked blue B.

Retrospective Report: I picked blue B because I knew the blue one needs to be out of the way and then I um, thought about if which the second column or the third column would be best for it. And that's all.

10. This one they're all out of order also, so the first thing that needs to move is the blocks on top of the yellow block which needs to be in the third column first
so that's the blue block so the first thing that needs to be done is to move the blue block to either the second or third column.
Um, I'm going to move it to the third column so I can later stack it to the second.

Retrospective Report: Blue to the third column because it was in the way of the yellow one which needed to move to the third column. So that's all I got.

11. Okay this one the bottom, the first block is in the right spot
so we just need to move all the blocks on top of the next one away
so that would be the blue one needed to be first.
So we need to move the blue one and it needs to go to either the second or third column.
So I'm going to pick the, the second column.

Retrospective Report: Blue to the second column because I knew that one needed the first one needed to be moved. I think that's it.

12. This one the first column's in the right spot but
there's two blocks on top of it that aren't in the right spot
so we needed to move them away and
the first one that needs to be moved is the blue one, and
I'm going to move the blue one to the first one
so I can later move the green one and
then stack it on top of that
so I'm going to put Blue A.

Retrospective Report: Blue A just because I knew it was in the way, I thought it was in the way of the yellow block so I moved it to the first column.

13. Okay, um two of the blocks are in the right spot
so I just need to make room for the third block but
it's covered by two other blocks
so that blue block on top of the red one that I need to move,
that one needs to move out of the way
so it either needs to go in the first or third column
so I'm going to pick blue and it needs to… I'm going to pick it to go to the third column because
then I can later move the green to the first column and
then the blue one on top of that and
then the red one on top of the blue.

Retrospective Report: So I picked the blue goes to the first column. And I just saw which blocks were in the way of the one I needed to move and moved them in the right order just so I knew they would stack properly.

14. In this one all I need to do is just move the blue one to the second column
because I can already see that the green one can easily move to the top of the stack and
then the blue.

Retrospective Report: I just moved the blue to the second and that didn't take much thought because I just saw it really fast.

15. This one they added one… a color and
they all need to be moved over to the third column and none of them are in the right spot.
So the first one that should be moved is… Um, I'm going to pick the red one and move it…
Um, I'm going to move the, this one.
I'm going to move the red one to the first one.

Retrospective Report: I don't remember what I thought I was just trying to think and then I got confused. So I'd move the red one out of the way for the third column and that's all I remember.

16. Okay for this one they're all in like the wrong spot.

The yellow one needs to move to the third column
so I'm just going to start moving the third column off of it so I can move the yellow one there.
So I'm going to move the purple one to the first column to get it out of the way first.

Retrospective Report: I just moved the purple to the first column just to make room for the yellow one to get there eventually.

17. And for this one they're all out of order and
the yellow one needs to get in the third column first but
it has blocks on top of it
so I want to move that top block first to make room for the other ones.
So I'm going to I think either way I'd be able to get, like have enough steps to move it.
So I'm just going to move the purple one to the first column.

Retrospective report: Move the purple to the first column just to get that block out of the way to eventually move all the blocks over and get the yellow one to the third column first.

18. And this one the first block's already in place but
the second block is stacked with other blocks on top
so I need to start getting that first block off
so the purple one needs to move um, out of the way
to I'm going to say… The third block.

Retrospective Report: I moved the purple to the third block um so I could eventually move the blue one to the yellow. That's all I can remember.

19. Um, this one I need to move the blue block to the second column,
to the third column because the yellow one's already there.
So I want to start emptying the third column out so I can put that there
so I'm going to move the purple one to the second column
so I can later move the blue one and the green one.

Retrospective Report: I moved the purple to the second column so I could eventually move the second block on top of the yellow block.

20. For this one two of the blocks are in the same, are in the right position
so all I need to do is find the third block which is covered by blocks
so I obviously need to move the first block first which is the purple one, and
I want to move that to the third I think. To the third.
Wait… No I'm going to move it to the second just because if not I'm not going to be able to move the red one eventually
because the blocks are going to be too small
because I can't stack a big block on top of a small block.
So move it to b.

Retrospective Report: I moved the purple one to B so I could eventually move the red one to the third column and that was one way that they could all fit.

21. For this one three of the blocks are in the right position
so I need to find the fourth block
which is covered by two other blocks.
I'm going to move the purple out of the way and
I'm going to put it on the third block.

Retrospective Report: Purple to the third block because I thought that the green one needed to be on top of the third I need to move the other two away so I started moving them.

22. Um, all of them are in the wrong position
so I need to just start moving them off the yellow block which is the first block
so I'm going to move the purple one to the second column
so I can eventually move the other two to the other side and move them back
so I could move the yellow one.

Retrospective Report: I moved the purple to the second column because I needed to move it out of the way and that's all I can remember.

23. Okay for this one they're all in the wrong position and
I need to eventually move the yellow one first to the third column
so I need to move the first block on top of that which is the purple block and
I'm going to move it like the last one to the second column.

Retrospective Report: I'm going to move the purple block to the second column because I needed to move the two ones underneath it and that was the way I thought that would be best to stack them and make room for the last one to move.

24. For this one they're all out of order and
the yellow one's by itself but it needs to move over to the third column
so we need to empty the third column to move that.
So we need to start stacking them on the second column and
the way to do that is to first move the purple to the first column and
eventually can move back to the second column and
empty the third column to make way for the yellow block.
So purple to B.

Retrospective Report: I picked purple to B because it was the best way to, in order to stack the blocks from biggest to smallest and make room for the, and empty the third column for the yellow block.

25. Okay for this one the yellow block's in the right position but the other ones aren't
so I need to find the second block which is blue and
I need to get rid of all of the blocks on top of the blue one
so I'm going to move the purple one first and
I'm going to move it to the third column.

Retrospective Report: Move the purple to the third column because I need to, I figure I needed to make space for the blue one to leave later to the third column.

26. For this one the first block is in the right position and
the second one I need to move is the blue one but
it is covered by the red one but I can't move that,
the red one because the only way I can move it is to the yellow one that's the wrong position
so the first thing I have to do would just be to move the purple block and
move them all over and get the red one off of the second column.
So I needed to move the purple one to the second column. I believe.

Retrospective Report: Um, I figured I didn't need to move the red one even thought it was blocking the blue because I couldn't put it anywhere that would.. um.. because the red doesn't go after the yellow so I'd move the purple block to move the red one over later.

27. Two of the blocks are in the right position and
the third block is… covered by a block
so I'm going to get rid of the first block which is on top of the third block which is the purple block and
I'm going to move it to the third row.

Retrospective Report: I picked purple block to the third row because I needed to get that third block to stack on the third row later and that was the first block blocking it so I moved it away.

28. For this one three of the blocks are in the right position
so I need to um find the fourth block which is green but
it's covered by two other blocks
so I first need to move that top block away and that's the purple block and
I need to move it to the third column.

Retrospective Report: I picked the purple block to the third column because it was in front it was on top of the fourth block which needed to be moved to the third column so I moved that away from it.

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BIOGRAPHICAL SKETCH

Tyler J. Towne was born in Wichita, KS. He earned his bachelors with honors in Psychology and a minor in Sociology from Florida State University. He completed his honors thesis leading to this work under the direction of Dr. K. Anders Ericsson. His current interests are skill development and the relationship between performance and general cognitive abilities over the course of skill acquisition.