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YALE UNIV NEW HAVEN CT DEPT OF PSYCHOLOGY  
COMPONENTIAL APPROACHES TO THE TRAINING OF INTELLIGENT PERFORMA--ETC(U)  
APR 80 R J STERNBERG, J L KETRON, J S POWELL N00014-78-C-0025

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## Componential Approaches to the Training of Intelligent Performance

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Technical Report No. 22  
April, 1980

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This research was sponsored by the Personnel and  
Training Research Programs, Psychological Sciences  
Division, Office of Naval Research, under Contract  
No. N0001478C0025, Contract Authority Identification  
Number NR 150-412.

ADA 086851

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report No. 22	2. GOVT ACCESSION NO. AD-A086851	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (and Subtitle) 6 Componential Approaches to the Training of Intelligent Performance		5. TYPE OF REPORT & PERIOD COVERED Periodic Technical Report 1 Jan 80 - 31 Mar 80
7. AUTHOR(s) 10 Robert J. Sternberg, Jerry L. Ketron, & Janet S. Powell		8. CONTRACT OR GRANT NUMBER(s) N0001478C0025 A A A
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Psychology Yale University New Haven, Connecticut 06520		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61153N; 16 RR 042-041 RR 042-041 NR 150-412
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research (Code 458) Arlington, Virginia 22217		12. REPORT DATE 11 1 Apr 80 12 5A
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 15 IN 11714-78-2-0025		13. NUMBER OF PAGES 32
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited 143 RR-1-80, TR-22		15. SECURITY CLASS. (of this report) Unclassified
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from report)		
18. SUPPLEMENTARY NOTES Portions of this paper were presented at the annual meeting of the American Educational Research Association, Boston, April, 1980. Intelligence, in press.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Intelligence, education, training, human abilities		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) NE This article proposes that 'componential' approaches to the training of intelligent performance are a useful means for producing and understanding improvements in such performance. <del>We buttress our proposal by citing outcomes (some of the preliminary) from three experiments conducted at Yale.</del> <sup>ARE</sup> <sup>ED.</sup> The results of these experiments show that at least some optimal strategies for intelligent performance can be trained; that certain strategies are better, on the average, than others; that the properties of		

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strategies that make them \*better\* or \*worse\* can, at least in some cases, be isolated through componential means; that certain strategies are preferable for people with certain ability patterns, but that other strategies are preferable for people with other ability patterns; that certain strategies are preferable for use with certain stimulus types, but that other strategies are preferable for use with other stimulus types; and that people may be quite cognizant of the strategy they are trying to employ while at the same time being quite incognizant of the strategy they are actually employing, or of the difference between the two strategies.

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Componential Approaches to the  
Training of Intelligent Performance

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Running head: Componential Approaches

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Abstract

This article proposes that "componential" approaches to the training of intelligent performance are a useful means for producing and understanding improvements in such performance. We buttress our proposal by citing outcomes (some of them preliminary) from three experiments conducted at Yale. The results of these experiments show that at least some strategies for intelligent performance can be trained; that certain strategies are better, on the average, than others; that the properties of strategies that make them "better" or "worse" can be isolated through componential means; that certain strategies are preferable for people with certain ability patterns, but that other strategies are preferable for people with other ability patterns; that certain strategies are preferable for use with certain stimulus types, but that other strategies are preferable for use with other stimulus types; and that people may be quite cognizant of the strategy they are trying to employ while at the same time being quite incognizant of the strategy they are actually employing, or of the difference between the two strategies.

Componential Approaches to the  
Training of Intelligent Performance

The past decade has witnessed a powerful resurgence of interest in the nature and training of intelligent performance. Research conducted during this decade has been largely guided by an information-processing approach to intelligence, rather than by the psychometric (or factorial) approach that guided much earlier research. Facets of intelligence that were formerly studied in terms of structural models based upon patterns of subject variation in task performance have now been studied as well in terms of process models based upon patterns of stimulus variation in task performance. Examples of facets that have been so studied are verbal ability (e.g., Hunt, 1973; Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975), reasoning ability (e.g., Pellegrino & Glaser, in press; Sternberg, 1977; Sternberg, Guyote, & Turner, 1980; Whitely & Barnes, 1979), problem-solving ability (e.g., Newell & Simon, 1972; Siegler, 1978), spatial ability (e.g., Cooper & Shepard, 1973; Egan, 1979; Shepard & Metzler, 1971), and memory ability (e.g., Belmont & Butterfield, 1971; Brown, 1975; Campione & Brown, 1977; Horn, in press). The psychometric and information-processing approaches to the understanding of intelligence are largely complementary, focusing as they do upon different kinds of variation in task performance. But the information-processing approach has been particularly fruitful in suggesting directions for training intelligent performance, perhaps because of its emphasis upon the processes and strategies people use in intelligent behavior (Sternberg, in press-a, in press-b). Impressive training outcomes have been achieved in domains as diverse as reasoning (Feuerstein, 1979a, 1979b; Holzman, Glaser, & Pellegrino, 1976; Trabasso, Riley, & Wilson, 1975), problem solving (Klahr, 1978; Siegler, 1978), and memory (Belmont

& Butterfield, 1971; Butterfield, Wambold, & Belmont, 1973; Brown & Campione, 1977; Wanschura & Borkowski, 1975).

Our own approaches to understanding and training intelligent performance have been guided by an approach characterized by its blend of information-processing and psychometric techniques. Our particular blend of the two techniques, which is only one of many such blends (e.g., Carroll, 1976; Hunt et al., 1973; Jensen, 1979; Mulholland, Pellegrino, & Glaser, in press; Snow, 1979), has been referred to as "componential analysis" (Sternberg, 1977, 1978, 1979, 1980, in press-b). A major goal of componential analysis is to isolate information-processing components of intelligent task performance, and to relate these components to each other and to performance on standard psychometric tests and factors of intelligence. We believe the approach has been at least somewhat successful in helping us understand the nature of intelligent performance. During the past few years, we have been asking whether any of this understanding can be translated into a program of action for training intelligent performance. In this article, we list some of the questions we have been asking about training of intelligent performance, and describe some of the research we have done and are currently doing that is addressed to these questions.

The questions that have guided our research are these:

1. Can optimal strategies for intelligent performance be trained?
2. Are certain kinds of strategies better, on the average (over people and stimulus types), than others?
3. What is it about certain strategies that makes them better (or worse) than others?
4. Are certain strategies preferable for people with certain ability patterns, and other strategies preferable for people with other ability patterns?

5. Are certain strategies preferable for certain stimulus types, and other strategies preferable for other stimulus types?

6. What information do people have about the strategies they are using and that they should be using?

The remainder of this article describes research we have done and are doing that addresses these questions. We draw in particular upon three training studies, one using deductive problems, namely, linear syllogisms (Sternberg & Weil, 1980); a second using inductive reasoning problems, namely, analogies (Sternberg & Ketron, 1980); and a third using verbal comprehension problems, namely, inferring meanings of unfamiliar words presented in familiar kinds of written contexts (Powell & Sternberg, 1980).

#### Can Optimal Strategies for Intelligent Performance be Trained?

The research of Holzman, Glaser, and Pellegrino (1976) on training of performance on series extrapolation problems suggested that information-processing strategies can be trained at least to some extent, and our research outcomes are consistent with those of Holzman et al.

In our linear-syllogisms training study (Sternberg & Weil, 1980), college-age subjects were asked to solve problems such as "John is taller than Pete. Pete is taller than Bill. Who is tallest? John, Pete, Bill." Problems were presented to subjects tachistoscopically, and subjects pressed a button indicating response choice. Subjects were timed as they solved the problems; they were told to solve the problems as quickly as they could without making errors. Subjects were divided into a control group and two experimental groups. Control-group subjects were given no explicit instruction as to how to solve the problems. Experimental-group subjects were told that although there are many ways of solving these problems, they should use the method in which they would be instructed. Subjects in a "visualization" group were told to try to organize

the statements into a spatial array or a series formation. The important thing, they were told, was to try to visualize the relationships described in the statements. Subjects were shown examples of different pictorial arrays that might correspond to what they would construct in their heads. They were told that they could use any of the pictorial formats, or some other format, so long as they used some pictorial representation to solve the problems. Subjects in an "algorithmic" group were told to read the final question first, then to read the first statement, then to answer the question in terms of the first statement ("John" in the example), and finally to scan the second statement. If the answer to the first statement was not contained in the second statement (as in the example, where "Pete" and "Bill," but not "John," appear in the second statement), the answer to the first statement then was also the correct response to the entire problem (hence "John" is the correct response in this problem). If the answer to the first statement was contained in the second statement, then the other answer choice in the second statement was the correct response to the entire problem. This algorithmic strategy, suggested by Quinton and Fellows (1975), works successfully for any linear syllogism in which it is possible to determine the full ordering of all three terms. All linear syllogisms in the experiment did, in fact, have fully determinate orderings of terms. Consider now some basic statistics from the data collected for the linear syllogisms.

Mean solution latency was 7.03 seconds in the untrained group, 7.18 seconds in the visualization group, but only 4.51 seconds in the algorithmic group. The algorithmic strategy was thus much more time-efficient than the visualization strategy or the strategy used by the untrained subjects, although the substantial decrease in latency was bought at some expense in accuracy. Mean error rates were 1.7% in the untrained group, 2.0% in the visualization group, and 3.5% in

the algorithmic group. Training had some effect, at least in the last group.

These results raised as many questions as they answered. First, what were subjects in the untrained group doing, and did it differ from what subjects in the visualization group were doing? Second, were instructed subjects doing what they were trained to do? Third, if at least some instructed subjects were not doing what they were trained to do, what were they doing? These questions could be answered by analyzing data at the level of individual subjects. Latency data for each subject were mathematically modeled using componential modeling techniques (see Sternberg, 1977, 1980a, 1980b). Four alternative models were fit to each subject's latency data. These models (described in detail in Sternberg, 1980b) asserted that subjects solved the linear syllogisms using either the short-cut algorithmic strategy, which all but bypasses the need for reasoning operations, or that subjects solved the items using reasoning operations working on either a linguistic data base, a spatial (imaginal) data base, or a combination of the two. Subjects were then classified as using the strategy represented by the model best fitting their individual data.

In answer to the first question, that of what subjects in the untrained group were doing and how it differed from what subjects in the visualization group were doing, almost two-thirds of the untrained subjects were using a reasoning strategy operating upon a combination of linguistic and spatial data bases; the remaining subjects were approximately equally split in their use of the other three strategies. The proportions of subjects using each strategy were almost identical in the visualization group, suggesting that when trained to use visualization, subjects do pretty much what they would have done without training.

In answer to the second question, that of whether instructed subjects

were doing what they were trained to do, at least three-fourths of the subjects in the visualization group were using a strategy that required visualization (either the strategy acting upon a spatial representation or the one acting upon both a linguistic and a spatial representation). In the algorithmic group, although subjects were about four times as likely to use the algorithmic strategy as were subjects in either of the other two groups, only slightly fewer than half of the 48 subjects appear actually to have used the algorithmic strategy.

In answer to the third question, that of what instructed subjects were doing who were not doing what they were trained to do, about the same number of subjects in the algorithmic group used the reasoning strategy operating upon a linguistic and a spatial representation as used the algorithmic strategy. The few remaining subjects used either the linguistic or the spatial strategy. Thus, the algorithmic training was successful in converting many, but not all subjects to use of the short-cut algorithm. Visualization training was consistent with what most subjects did anyway, and probably had little effect.

In our analogies study (Sternberg & Ketron, 1980 ), data for 96 subjects (half of the target number we shall eventually test for the study) have been collected and analyzed. These college-age subjects were asked to solve analogies of the form  $A : B :: C : (D_1, D_2)$ , where analogy terms were schematic pictures of people. These pictures varied on four binary dimensions. The pictures were of two kinds. One kind varied in height (tall-short), shading of clothing (black-white), sex (male-female), and weight (fat-thin). The other kind varied in hat color (black-white), vest pattern (striped-polka-dotted), handgear (briefcase-umbrella), and footwear (shoes-boots). The critical difference between the two kinds of stimuli was that stimuli of the first kind possessed perceptually integral attributes, which tend to be processed holistically, whereas stimuli

of the second kind possessed perceptually separable attributes, which tend to be processed analytically (see Garner, 1974; Sternberg & Rifkin, 1979). No subject saw more than one kind of stimulus attribute. Analogies were presented tachistoscopically, with subjects being told to solve the analogies as quickly as they could without making errors. Subjects receiving each kind of analogy were equally divided among one control group and three experimental groups. Each group received different instructions.

Subjects in the control group were not trained in any particular strategy for analogy solution. They were told simply to solve the analogies in whatever way they wished. Subjects in the experimental groups all received training of the following three kinds.<sup>1</sup>

In a fully "exhaustive" training condition, subjects were trained to infer all four possible relations between the A and B (first and second) analogy terms (e.g., height might change from tall to short, shading remain black in both pictures, sex remain male in both pictures, and weight change from fat to thin), and to apply all four inferred relations from the C (third) analogy term in order to select the correct D (fourth) analogy term (e.g., height would have to change from tall to short, shading remain black, sex remain male, and weight change from fat to thin). In this strategy, then, subjects always inferred and applied all four attributes.

In a fully "self-terminating" training condition, subjects were trained to infer one relation (of their choice) from A to B (e.g., that height changes from tall to short), and immediately to apply this relation from C to D. If that relation distinguished the correct answer option from the incorrect one (e.g., C was tall but only one of the two answer options was short), then subjects were to select the correct option at once. If the attribute did not distinguish between options (e.g., if both options were short), then subjects

were to select another attribute (of their choice) and to attempt to choose an answer option on the basis of a distinction between options in their values on that attribute. This procedure was to continue until the correct answer could be distinguished from the incorrect one. In this strategy, then, subjects inferred and applied the minimum possible number of attributes (given their idiosyncratic order of selection of attributes) needed for selecting the correct answer.

In a "mixture" training condition, subjects were trained to infer all four possible relations between the A and B analogy terms, but to apply only as many of those relations as they needed to distinguish the correct answer from the incorrect one. In other words, inference was exhaustive, but application was self-terminating: Subjects inferred all possible relations between A and B, but applied only the minimum possible number of relations from C to D. Consider now some mean data from these four conditions.

Mean solution latencies for stimuli with integral attributes were 2.87 seconds for untrained control subjects, 9.02 seconds for exhaustive training subjects, 3.10 seconds for self-terminating training subjects, and 5.46 seconds for mixture training subjects. Error rates were 4%, 4%, 5%, and 3% for the four respective groups. Mean solution latencies for stimuli with separable attributes were 2.78 seconds for untrained control subjects, 7.13 seconds for exhaustive training subjects, 2.77 seconds for self-terminating training subjects, and 4.69 seconds for mixture training subjects. Error rates were 2%, 5%, 3%, and 5% for the four respective groups. Training had some kind of effect

What were subjects in the various groups actually doing? Although both group and individual data were modeled componentialy, the individual data were not of sufficient reliability to allow conclusions to be drawn with confidence; hence, we shall concentrate upon group data. Seven alternative

models were fit to the latency data for each group. There were more models than there were training groups because no instruction was given in two components of information processing that appear in a full information-processing model of analogical reasoning (Sternberg, 1977; Sternberg & Rifkin, 1979). These two components are encoding of stimulus terms, which can be either exhaustive or self-terminating with respect to the (four) attributes of each analogy term, and mapping, the perception of the higher-order relations between the first and second halves of the analogy, which can also be either exhaustive or self-terminating. The seven models (see Sternberg & Rifkin, 1979) were

- Model I: encoding, inference, mapping, and application exhaustive;
- Model II: encoding, inference, and mapping exhaustive;  
application self-terminating;
- Model III: encoding and inference exhaustive;  
mapping and application self-terminating;
- Model IV: encoding exhaustive;  
inference, mapping, and application self-terminating;
- Model IM: inference and application exhaustive;  
encoding self-terminating (but mathematically indistinguishable  
from exhaustive);  
no mapping;
- Model II- inference exhaustive;
- IIIM: encoding and application self-terminating;  
no mapping;
- Model IVM: encoding, inference, and application self-terminating;  
no mapping.

Consider first model fits for subjects receiving analogies with integral stimulus attributes. Data for subjects in the untrained control group were

best fit by Model IV, with Model III a close competitor. In previous experiments (Sternberg, 1977; Sternberg & Rifkin, 1979), data for comparable subjects were best fit by Model III (which differs from Model IV only in inference being exhaustive rather than self-terminating), with Model IV a close competitor, so that these results are close, but not identical to previous ones with these stimuli. Data for subjects trained to use full self-termination should be best fit by either Model IV or IVM in order for these data to be compatible with the kind of training the subjects received. In fact, the group data were best fit by Model IVM. On the average, therefore, subjects in this group did as they were instructed, that is, they followed a strategy with full self-termination, one that was similar but not identical to the strategy followed by uninstructed subjects. Data for subjects trained to use fully exhaustive processing should be best fit by either Model I or IM in order for these data to be compatible with the kind of training subjects received. In fact, the data were best fit by Model I, although there were suggestions in the data that some of the subjects used Model II at least some of the time. In general, though, these data, too, were consistent with the training subjects received; but as could be inferred from the large mean difference between latencies for this group and the untrained group, the strategy followed by subjects in this group differed radically from that followed by untrained subjects. Finally, data for subjects trained to use mixed exhaustive and self-terminating processing should be best fit by any of Models II, III, or II-IIIM in order for the data to be compatible with the kind of training the subjects received. In fact, the data were best fit by Model III. Thus, these subjects, too, followed instructions, and differed from the untrained subjects only in their use of exhaustive rather than self-terminating inference. To summarize, subjects receiving strategy training for analogies with integral

attributes generally followed the strategy they were trained to use.

Consider next model fits for subjects receiving analogies with separable stimulus attributes. Data for subjects in the untrained control group were best fit by Model IVM. In a previous experiment (Sternberg & Rifkin, 1979), data for comparable untrained subjects were also best fit by Model IVM, so that these results were completely consistent with ones obtained in earlier research. Data for subjects trained to use fully self-terminating processing (which should be best fit by Model IV or IVM to be consistent with training) were in fact best fit by Model IVM. Thus, these subjects followed the same strategy as did subjects who were trained to use fully self-terminating information processing for the analogies with integral stimulus attributes. Data for subjects trained to use fully exhaustive processing (which should be best fit by Model I or IM to be consistent with training) were in fact best fit by Model IVM (which is quite different in character from either of Models I or IM), although one parameter (self-terminating encoding) could not be reliably estimated for this group. Thus, it appears likely that subjects in this group did not follow their training instructions, although it is not clear exactly what these subjects did do. Finally, data for subjects trained to use mixed exhaustive and self-terminating processing (which should be best fit by any of Models II, III, or II-IIIM to be consistent with training) were best fit by Model IVM as well, although there was evidence that at least some subjects used Model II-IIIM. Again, strategy usage was not consistent with training. To summarize, subjects receiving strategy training for analogies with separable attributes generally did not follow the strategy they were trained to use, perhaps because Model IVM is so "natural" in some sense for these stimuli: No subjects have been found who use any other model.

In our verbal comprehension study (Powell & Sternberg, 1980), data have

been subjected to only the most rudimentary analyses, so our emphasis will be upon describing what we are attempting to accomplish and how we are attempting to accomplish it. A major purpose of the study is to find out how subjects (high-school students) learn, retain, and transfer meanings of unfamiliar words presented in familiar kinds of contexts.<sup>2</sup> For our present purposes, however, we shall dwell upon a subsidiary purpose of the study, that of training subjects to learn, retain, and transfer meanings of unfamiliar words presented in context.

All subjects in the study received a set of 33 brief reading passages such as might be found in newspapers, magazines, novels, or textbooks. Embedded within these passages were from one to four very low-frequency words, which could be repeated from zero to four times either within or between passages, but not both. Examples of two such passages, which differ considerably in content, are the following:

The ultimate goal of those seriously involved in raising livestock is to produce animals with a high percentage of top quality meat and a low percentage of waste. Recently, livestock breeders have successfully developed a new breed of turkey whose haeccity is its high proportion of breast meat to dark meat. The most efficient way to improve stock, practiced by many ranches, is to hire a thremmatologist to advise in the purchase and mating of different breeds. The thremmatologist carefully researches the characteristics of each breed involved and then examines the bloodlines of the specific animals under consideration. The success resulting from this scientific monitoring perhaps justifies the jactancy of its proponents, who belittle the old trial-and-error methods and foresee a new age of made-to-order livestock.

Two ill-dressed people--the one a tired woman of middle years and the other a tense young man--sat around a fire where the common meal was almost ready. The mother, Tanith, peered at her son through the oam of the bubbling stew. It had been a long time since his last ceillidh and Tobar had changed greatly; where once he had seemed all legs and clumsy joints, he now was well-formed and in control of his hard, young body. As they ate, Tobar told of his past year, re-creating for Tanith how he had wandered long and far in his quest to gain the skills he would need to be permitted to rejoin the company. Then all too soon, their brief ceillidh over, Tobar walked over to touch his mother's arm and quickly left.

Subjects were divided into two experimental and two control groups. In the first experimental group, subjects were asked to provide ratings regarding the low-frequency words and their surrounding contexts. These ratings were of (a) how concrete versus abstract each word was; (b) how helpful the part of the passage preceding the occurrence of the low-frequency word was in deciding what the word meant; (c) how helpful the part of the passage following the occurrence of the low-frequency word was in deciding what the word meant; (d) how helpful the passage as a whole was in enabling the subject to decide what the word meant; (e) how important the low-frequency word was to understanding the main idea of the sentence in which it was used; and (f) how important the low-frequency word was to understanding the main idea of the passage in which it occurred. When a given word occurred more than once in a given passage, subjects were also asked to rate how helpful the part of the passage between occurrences of the word was in deciding what the word meant.<sup>3</sup> In the second experimental group, subjects were asked to state the main idea of the passage and to

define as best they could each of the underlined (low-frequency) words. When a single word appeared twice in a passage, they only needed to define it once, but if a given word appeared again in a later passage, subjects had to redefine the word later on. Subjects were allowed to view the passage they had just read at the time they defined the word, but they were not allowed to look back at previous passages. Subjects in the first control group were asked to read each of the passages, which were presented without punctuation or capitalization. The subjects' task was to provide punctuation and capitalization. Thus, subjects in this group had to understand at some level the contents of the passage in order to perform their task, but the attention of these subjects was drawn to aspects of the passage that were irrelevant to understanding the low-frequency words. Finally, subjects in the second control group never saw the passages at all.

All subjects received a pretest and a retest that contained passages very much like those in the main part of the study. The subjects' task was to read each passage and define the low-frequency words.

Our major training concern was with the extent to which the two kinds of training exercises would improve subjects' abilities to understand unfamiliar words presented in short passages. The dependent measure was improvement from pretest to retest for each of the experimental groups in comparison to each other and to each of the control groups. Our very preliminary data analyses indicate success for the training procedures in that subjects became more aware of how to define a word presented in context, but we are not yet in a position to evaluate our findings in an informed way.

Are Certain Kinds of Strategies Better, on the Average, than Others?

The three experiments described above all have implications for answering this question, and on the basis of our observations, we believe the answer is clearly affirmative.

In the linear-syllogisms experiment, the algorithmic strategy resulted in a large decrease in mean solution latency, although at the expense of some increase in error rate. In this particular case, the strategy was one that few subjects adopted spontaneously, but was one that many subjects could be trained to use with just about 10 to 15 minutes of instruction. The strategy does have a disadvantage, namely, its limitation to fully determinate problems (i.e., ones in which the complete ordering of the three terms can be inferred from the problem statement); also, it is not clear how the strategy would be generalized to linear ordering problems with more than three terms, e.g., John is taller than Bill; Bill is taller than Pete; Pete is taller than Mike; who is tallest? The model with the second lowest mean latency, and with a lower error rate, is the mixture model, which involves representations of information both linguistically and spatially. Thus, this model might be the most efficacious one from the standpoint of generality as well as efficiency of information processing.

In the analogies experiment, the self-terminating Models IV and IVM appear to have been the most efficacious ones for subjects to use. They resulted in the lowest solution latencies, and were not associated with particularly high error rates in this experiment. Most subjects left to their own devices appear to have used either Model IV (analogies with integral attributes) or Model IVM (analogies with separable attributes), and subjects instructed to use a self-terminating model had the lowest solution latencies of any instructed group. For analogies with separable attributes, we had little success in getting sub-

jects to use any model other than IVM, making it difficult to compare results for different strategies. Previous research is consistent with the present research in suggesting that for analogies with separable attributes, subjects as young as seven years of age and as old as adulthood use Model IVM spontaneously (Sternberg & Rifkin, 1979). This same research found a transition over age in model usage for analogies with integral attributes, however. Second-graders (about seven years of age) used Model IVM, fourth-graders (about nine years of age) used Model IV, and sixth-graders through adults used Model III. The empirical data have never distinguished well between Models III and IV, however, and it is quite possible that subjects either alternate over time in their use of one model or the other, or that there are individual differences in which subjects use each of these two models.

We do not yet have sufficient data from the verbal-comprehension study to compare the efficacy of alternative strategies used within the learning-from-context paradigm. We suggest, however, that if one's goal is to improve vocabulary, learning strategies for inferring meanings from context is superior, on the average, to merely memorizing meanings of words from a dictionary or similar source, for reasons to be discussed.

What is it about Certain Strategies that makes them Better or Worse than

Other Strategies?

The superiority of the algorithmic strategy for solving linear syllogisms can probably be traced to its mechanistic nature: Subjects essentially bypass the use of transitive inference by using a short-cut that provides a solution with minimal information processing. An analogue exists for solving categorical syllogisms (e.g., All B are C. All A are B. Can one conclude that All A are C?): A small set of rules enables one to pick out any of the relatively small subset of categorical syllogisms that is deduc-

tively valid (see Copi, 1978). But such short-cut strategies are of less interest than alternative strategies, because they capitalize upon specific features of certain item types and are not generalizable to problems even that are quite similar in structure (e.g., four-term linear syllogisms). The second most efficacious strategy for solving linear syllogisms, that characterized by the mixture model, may be more efficacious than the spatial and linguistic strategies because of its use of that form of representation at each stage of information processing that is most well suited to that particular stage of information processing. The alternative strategies may extend their single representations beyond those stages of information processing where they are most suitable.

The superiority of self-terminating strategies for analogical reasoning can be traced to the reduction in the number of component executions required for analogy solution (which can be substantial for analogies with terms having complex or numerous attributes) and to the reduction in load upon working memory that results from testing one attribute completely before moving on to consider any other attributes. But as was the case for linear syllogisms, the user of this highly efficient kind of strategy must beware. Previous research has shown that almost all errors made in analogical reasoning derive from execution of self-terminating (as opposed to exhaustive) information-processing components (within a given strategy) (Sternberg, 1977).

Finally, we would like to state why we speculate that acquiring strategies for inferring meanings of words from context is superior to memorizing lists of words if one's goal is to improve one's vocabulary. We believe that the former route has at least two advantages. First, our observations of vocabulary-learning in the real world persuade us that learning achieved through rote memorization of words is less durable than meaningful acquisition

of words encountered in natural contexts. Unless people see and use the memorized words frequently in everyday contexts, the meanings of the words are forgotten. Almost everyone has had the experience of seeing or hearing words whose meanings one once memorized but has since forgotten. We believe the meanings of words learned in context are more likely to be durable because the meaning can later be reinstated through association with the context, and because even if the meaning of the word is forgotten, if one's skills for learning meanings from context are sufficiently sharp, one can reinfer the meaning of the word from the new context. Second, we suggest that learning of meanings of words in context is more likely to be generalizable than learning of meanings of words in isolation. Words are often used with subtle and multiple shades of meaning that are conveyed in real-world, but not in dictionary, contexts. As one sees a word in multiple contexts, one essentially constructs the meaning of the word, building up a word-meaning representation that mimics in greater or lesser degree some ill-defined and probably not precisely definable "true" meaning. This active construction process results in a representation that is readily usable in everyday life.

Are there Person x Strategy Interactions?

Evidence from our linear-syllogisms research (as well as from the research of others; see, for example, Gavurin, 1967; MacLeod, Hunt, & Mathews, 1978) strongly suggests the existence of person (or aptitude) x strategy interactions. In the linear-syllogisms experiment, we correlated people's scores on orthogonal verbal and spatial ability factors with people's latencies for solving linear syllogisms. The correlations for the original groups were undifferentiated both across groups and across (verbal and spatial) abilities. Latencies were correlated with verbal and spatial abilities in each group, and there were no signs of interactions. Suspecting the possibility of multiple

strategies within (as well as between) groups, we modeled each subject's data individually, and discovered that there were indeed strategy differences within each group: Not every trained subject was doing what he or she was trained to do, and untrained subjects showed natural individual differences in strategy selection. We therefore re-sorted subjects into strategy groups on the basis of the individual modeling. We now found that latencies of subjects using the mixture model were significantly correlated with both verbal ability and spatial ability; latencies of subjects using the linguistic model were significantly correlated with verbal ability but not spatial ability; latencies of subjects using the spatial model were significantly correlated with spatial ability but not verbal ability; and latencies of subjects using the algorithmic model were significantly correlated with verbal ability and marginally correlated with spatial ability. Thus, the efficacy of a given strategy depended upon both the strategy and the subject's pattern of abilities.

In the analogies research, latencies for analogy solution were significantly correlated with an inductive reasoning factor score, but only for analogies with integral stimuli and only for untrained subjects. Training seems to have removed the correlation for the analogies with integral attributes, and the correlation was not found for analogies with separable attributes. It should be noted that analogies of the kind used in this experiment--ones with simple schematic-picture attributes--tend to yield lower correlations with ability tests than do other kinds of analogies with more complex attributes (Sternberg, 1977).

We have not investigated person x strategy interactions in the verbal-comprehension situation, although we are planning a study to investigate the hypothesis that for some subjects--those who do not have, or have great

difficulty acquiring, skills for learning meanings of words from context--rote learning of vocabulary is superior to contextual learning as a means for vocabulary building.

Are there Stimulus x Strategy Interactions?

None of several investigations of linear syllogistic reasoning provides any evidence of stimulus x strategy interactions. Subjects were tested with a variety of adjective pairs (taller-shorter, better-worse, older-younger, faster-slower), but strategy usage did not differ across these adjective pairs (Sternberg, in press-b, in press-c; Sternberg & Weil, 1980).

The analogies data show clear signs of a stimulus x strategy interaction. In the Sternberg-Ketron (1980) data, Model IV was preferred for analogies with integral attributes (but Model III was preferred in the Sternberg, 1977, and Sternberg & Rifkin, 1979, data), whereas Model IVM was preferred for analogies with separable attributes (as in the previous Sternberg-Rifkin, 1979, data). The Sternberg-Rifkin data showed an even more complex person x stimulus x strategy interaction: Model IVM was preferred for subjects of all ages when subjects solved analogies with separable attributes; but the preferred model changed with age--from Model IVM to Model IV to Model III--when subjects solved analogies with integral attributes.

The verbal comprehension study did not manipulate stimulus type, and hence contains no suggestions of stimulus x strategy interactions. We would expect, however, that one's purpose, e.g., reading the passages for comprehension versus reading the passages to learn the new words, would, in effect, redefine the task, and therefore would have an effect on which strategy is best.

What Information do People have about Strategies?

Our analogies study was conducted in part to explore the question of what impressions people have about various strategies they use. Each subject in each group received a questionnaire asking various questions about the strategy the subject had used in solving the analogies.

Consider first the questionnaire responses for subjects receiving analogies with separable attributes. In previous research, it has been found that subjects were well able to describe their thought processes in solving such analogies (Sternberg & Rifkin, 1979). In the present research, subjects' descriptions were highly consistent with the strategies the subjects were trained to use, but not consistent with the strategies subjects actually did use (at least, according to the mathematical modeling). The data suggest that subjects did in fact try to use the strategy they were trained to use; that their questionnaire descriptions correspond to what they were trying to do (although not, apparently, to what they actually succeeded in doing), and hence that subjects were aware of what they were trying to do; but that subjects were not fully aware of the discrepancy between what they were trying to do and what they actually were doing. And these discrepancies were striking. The group trained to use the exhaustive model, for example, showed an  $R^2$  of .53 between predicted and observed values for a fully exhaustive model (I or IM), but an  $R^2$  of .91 between predicted and observed values for a fully self-terminating model (IVM). Although this patterning of data was quite similar to that for the group trained to use the full self-terminating strategy (where the  $R^2$  for the fully self-terminating model was .94), the fact that subjects in the exhaustive training group were trying to do something different from what subjects in the self-terminating group were doing is shown by the fact that the mean solution latency in the exhaustive group was over 7 seconds, compared to less than

3 seconds in the self-terminating group. The former subjects were obviously trying to be exhaustive, although they were apparently less than fully successful in these efforts.

Subjects in the separable-stimuli group described the fully exhaustive strategy as slower (and less accurate) than the mixture strategy, which in turn was perceived as slower than the fully self-terminating strategy. These perceptions were, of course, accurate for the strategies as trained. The exhaustive and mixture strategies were perceived as more difficult both to learn and to maintain (over time) than was the self-terminating strategy. Indeed, subjects reported extreme difficulty in maintaining the exhaustive strategy, and the data indicate that subjects did indeed have extreme difficulty in maintaining this strategy. The exhaustive strategy was also reported correctly as requiring the greatest memory load; the self-terminating strategy was correctly reported as requiring the least memory load. Subjects in the exhaustive group reported having been the most conscious of the strategy they were executing; subjects in the self-terminating group reported having been least conscious of the strategy, with subjects in the mixture group in the middle. Overall, the exhaustive strategy was perceived as the poorest one and the self-terminating strategy as the best one, with the mixture strategy again in the middle. These reports accurately reflected the distribution of mean solution latencies. Almost no subjects in the exhaustive training group reported that they would have used the exhaustive strategy had they not been trained to use it. Slightly fewer than half of the subjects in the other two groups reported that they would have used the strategy they were trained to use (self-terminating or mixture) had they been untrained. Here, subjects trained to use the self-terminating strategy were inaccurate in their perceptions of what they would have done, since the data from the untrained

groups suggest that most subjects left to their own devices will in fact use a self-terminating strategy.

Consider now the questionnaire responses for subjects receiving analogies with integral attributes. In previous research, it has been found that such subjects were not as well able to describe their thought processes as were subjects solving analogies with separable attributes (Sternberg & Rifkin, 1979). In the present data, the descriptions of the former subjects were slightly less accurate with respect to what they were trained to do, but more accurate with respect to what they were actually doing.

Subjects in the integral-stimuli group correctly described the fully exhaustive strategy as slowest, the self-terminating strategy as fastest, and the mixture strategy as intermediate. The self-terminating strategy was described as easiest to learn and to use, the mixture strategy as hardest to learn and to use (despite the fact that mixture solution latencies were much lower than exhaustive ones). The exhaustive and mixture strategies were described as harder to maintain than the self-terminating strategy. The self-terminating strategy was correctly described as requiring less memory load than the other two strategies. Subjects using the exhaustive strategy were more conscious of their use of this strategy than were subjects using the other two strategies (as was the case for subjects in the separable-stimuli groups). Overall, the mixture strategy was described as worst, followed by the exhaustive strategy; the self-terminating strategy was described as by far the best. About one-fourth of the people in the exhaustive and mixture groups said they would have used the strategies they were trained to use had they been untrained. This estimate was certainly too high for the exhaustive training group. About two-fifths of the people in the self-terminating group said they would have used the trained strategy had they been untrained.

This estimate was probably too low.

To summarize, subjects' metacognitive knowledge about their strategies differed for separable and integral stimuli. Subjects were probably more aware of what they were trying to do with separable stimuli, but probably less aware of what they were actually doing, at least in the present analogy training paradigm.

#### Conclusions

We are optimistic that componential approaches to the training of intelligent performance can be successful in improving people's performance. We have shown that strategies for intelligent performance can be trained; that certain strategies are better, on the average, than others; that it is possible to determine why certain kinds of strategies are better or worse than others (at least within the limited domain we explored); that there exist both person x strategy and content x strategy interactions, as well as person x content x strategy interactions; and that people have available good information about what they are trying to do, but perhaps less good information about what they are actually doing. The goodness of the information may depend upon the type of stimulus, and probably depends upon the type of task as well. We believe that people's quality of metacognitive information might be measurably improved by training the people in a particular strategy, and then pointing out to them how this strategy differs (if at all) from the strategy either that is ideal for the task (on the average) or that people use spontaneously when they are untrained. Such a procedure would give people a baseline against which to compare what they are doing, and so make them more aware of the extent to which they are following instructions. It might also provide people with a better basis for perceiving the relative strengths and weaknesses of alternative strategies for problem solution. Ultimately, we hope it will be possible to train people in ways that will make them truly "more intelligent."

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## Footnotes

Preparation of this article and execution of the research described in this article were supported by Contract N000178C0025 from the Office of Naval Research to Robert J. Sternberg. The research was conducted while Jerry Ketron was supported by a Yale University Fellowship and Janet Powell was supported by a National Science Foundation Fellowship. The authors express their appreciation to Evelyn M. Weil for her valuable collaboration in the linear-syllogisms training research (Sternberg & Weil, 1980), and to Barbara E. Conway and Elizabeth Charles for valuable assistance in data analysis in the linear-syllogisms and analogies training research. This article is based upon a presentation at the annual meeting of the American Educational Research Association, Boston, April, 1980. Requests for reprints should be sent to Robert J. Sternberg, Department of Psychology, Yale University, Box 11A Yale Station, New Haven, Connecticut 06520.

<sup>1</sup>We knew when we undertook the analogies training research that most subjects spontaneously use an optimal or near-optimal strategy for analogy solution. The major theoretical question motivating our research was "What general characteristics of certain strategies make them either optimal or nonoptimal in reasoning performance?"

<sup>2</sup>A further description of this research can be found in Sternberg (in press-b).

<sup>3</sup>The primary purpose of these ratings was to quantify the independent variables manipulated in the experimental passages.

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