DOCUMENT RESUME

ED 302 589 TM 012 659

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TITLE Spatial Aptitude as Expertise; A Training Study.
PUB DATE 88
NOTE 15p.; Paper presented at the Annual Convention of the American Psychological Association (96th, Atlanta, GA, August 12-16, 1988).
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PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Ability; College Students; Computer Assisted Instruction; Higher Education; Individualized Instruction; Learning Processes; *Spatial Ability; *Test Coaching; Test Wiseness; *Training
IDENTIFIERS Analogy

ABSTRACT

Whether or not a short-term intervention program could improve performance on standardized figural analogy and surface development tests was studied through training 10 students from an introductory psychology class with relatively low scores on the figural analogies subtest of the Cognitive Abilities Test. An additional 10 students served as controls. Training, designed to improve spatial skills, strategic test-taking skills, and analogy solution skills, consisted of seven hour-long sessions, all but one of which were individualized, and included practice tests, task practice, and a computerized spatial game. Experimental and control groups did not differ in scores on pretests. No differences were found for the experimental group on the figural analogy posttest but a significant effect of training was found for the surface development test, generally considered more difficult. Follow-up testing at 2 months confirmed effects of training. Results suggest that non-verbal ability measures should not be considered "knowledge free." Three tables present study data. (SLD)

Spatial Aptitude as Expertise: A Training Study

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Standardized figural analogy tests comprise spatial problem-solving tasks, performance on which is both highly predictive of academic success and commonly used as a "knowledge-free" measure of general aptitude (Snow, 1980; Sternberg, 1977). Long assumed to reflect a fixed trait rather than a labile skill, the experimental study of the cognitive characteristics of performance on these problems has begun only recently. Most of this research has invoked an information-processing approach, in which individual differences are expressed solely quantitatively--in terms of the speed or efficiency of execution of fixed stages (e.g., Evans, 1968; Mulholland, Pellegrino & Glaser, 1980; Sternberg, 1977). An alternative approach applies the expert-novice paradigm to the study of figural analogy solution, and investigates qualitative differences between high and low scorers in problem representation and solution strategies (Bethel-Fox, Lohman & Snow, 1984; Just & Carpenter, 1985; Schiano, Cooper & Glaser, 1984).

There is a great deal of evidence that experts and novices differ qualitatively in strategies for initial problem representation, and that these differences determine both the ease and the probability of correct solution in a variety of problem domains (e.g., Hayes & Simon, 1976; Newell & Simon, 1972). For example, novices tend to classify problems in terms of shared surface features or loose perceptual similarities, while experts use more abstract, well-constrained transformational belationships, and do so in a more consistent and coherent fashion. These differing initial representations then impose differing processing constraints; experts are thus much more efficient than novices in the choice as well as the performance of domain-specific mental transformations (e.g., Chi, Feltovich & Glaser, 1981; Larkin, McDermott, Simon & Simon, 1980).

Similar qualitative differences between high and low scorers on standardized figural analogy tests has been observed in previous research in our laboratory. More specifically, high scorers were found to classify problems in terms of an abstract and highly organized structure, most often on the basis of highly precise and holistic spatial transformations (e.g., rotation, reflection). Alternatively, lower scorers appear to focus more on loose perceptual similarities among figures comprising problem terms (e.g., shape, shading), or on local and poorly-constrained spatial relations (Schiano, Cooper & Glaser, 1983). Converging evidence for this distinction has been found in divergent aptitude-related patterns of: a) memory errors for spatial transformations v figural relations (Schiano, Cooper & Glaser, 1985), b) strategic eye movements in viewing specific problem terms during solution (Schiano, Cooper & Glaser, 1986), and c) verbal protocols during encoding and inference of figural analogy pair relationships (Schiano, 1986).

In addition, qualitative differences in test-taking strategies have also been found. Patterns of eye-movements during analogy solution indicate that high scorers use a kind of top-down, generate-and-test strategy, whereas low scorers are much more likely to use a less efficient bottom-up approach, focussing on answer alternative elimination rather than on the generation of--and comparison with--an "ideal" solution (Schiano, Cooper & Glaser, 1986). Moreover, there is some evidence that low scorers do not exploit the dual nature of analogies to the same extent that high scorers do. That is, in any analogy problem, when the

"A:B::C:D" relation holds, then "A:C::B:D" must also hold. Spontaneous introspective reports indicate the strategic use of this property of analogies by high scorers only (see Schiano, Cooper & Glaser, 1984).

To the extent that individual differences in performance on these standardized tests are truly similar to skill differences in problem solving, it might expected that low scorers should benefit from appropriate training. The study to be described here was designed to explore whether a short-term intervention program can be demonstrated to improve performance on standardized figural analogy tests. Unlike previous attempts to train spatial abilities (see McGee, 1979; Just & Carpenter, 1985), the training procedure used in this experiment was theory-driven and highly structured in application. Based on our earlier findings, the procedure was designed to improve both spatial (spatial representations and transformations) and strategic (test-taking and analogy solution) skills.

Method

Subjects.

Twenty subjects from a large Introductory Psychology class, scoring 17/25 or below on the Cognitive Abilities Test (CAT) figural analogies sub-test (Thorndike & Hagen, 1971), participated in this study. Half the subjects were in the experimental and control groups, respectively.

Design.

This experiment involved a pre-test, training, post-test and follow-up testing sequence. The control group participated in all but the training sessions; all testing was done on both groups simultaneously.

Stimuli.

All test stimuli for this experiment were taken directly from actual CAT test batteries; pre- and post-tests were taken from different Forms of the CAT. Training stimuli (for the practice and generation tasks) were constructed by systematically transforming CAT test problems, including: a) the addition of a spatial (rotation or reflection) transformation of problem terms, b) inversion ("A:C::B:D") of the analogy terms, and c) both of the above. Follow-up stimuli were similar to those used in the training sessions, but were derived from a different CAT Form.

Procedure.

Pre-testing took place in a group testing session, and included the figural analogies and surface development sub-tests of the CAT. Training comprised seven hour-long sessions, all but one of which were conducted individually. The first session involved a group lecture on spatial test-taking strategies, derived from our previous findings on aptitude-related differences on figural analogy tasks. The rest of the sessions, spread out over a four-week interval, consisted of: a) a practice test, of the same length and duration as the CAT test; b) a generation task, in which subjects were required to draw the correct answer to a complex problem, without recourse to multiple-choice answer alternatives; and c) a computerized game, in which subjects could request and view specific rotations and reflections of a variety of figures similar to those used on the CAT. Feedback was given after performance of each task as specifically and as immediately as possible. While playing the computer game, subjects were asked to first imagine the rotated figure, and then to compare the actual result to the imagined one. When errors were made in any of the tasks, subjects were required to "learn by doing" and literally manipulate the figures--using transparent copies--to transform the "C" term into the correct answer ("D"). To enhance motivation, subjects were given a small monetary award ($.05) for each correct answer in the practice tests. The post-test involved group testing session held about two weeks after the last training session. Follow-up testing was conducted over two months after the post-test. It comprised a timed test similar in nature--though not in specific items--to the practice tests, as well as three "generation" problems, for which subjects were asked to provide a written protocol of solution strategies.

Results and Discussion

As can be seen in Table I, the experimental and control groups did

Insert Table I about here

not differ in their scores on either the figural analogies ($t(18)=.53$ n.s.) or the surface development ($t(18)=.04$, n.s.) pre-tests. The effect of training was examined by testing for a significantly larger pre-test/post-test difference in the experimental group, for each spatial test. No difference was found for the figural analogy test ($t(18)=1.3$, n.s.), but--somewhat surprisingly--a significant effect was demonstrated for the surface development test ($t(18)=2.3$, $p<.05$), which is generally considered a more direct and difficult test of rotation and reflection abilities than the figural analogies test.

Additional analyses were undertaken in order to investigate the effects of training more closely. Analogy problems from both the pre- and post- tests were broadly classified as either spatial (requiring rotations and/or reflections) or figural problems (all other problems). Table II illustrates percent correct for the experimental and control groups on spatial and figural problems in the pre- and post-tests. No

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Insert Table II about here

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significant difference was found between the experimental and control groups on the pre-test for either the spatial ($t(18)=1.34$, n.s.) or the figural ($t(18)=.54$, n.s.) problems. More importantly, however, a significant training effect *was* found for the spatial problems ($t(18)=1.98$, $p<.05$), when considered independently. This was not the case for the figural items ($t(18)=.13$, n.s.). These results, together with the fact that the effects of training apparently transferred to performance on the surface development test, suggest that the specific post-test used did not provide an ideal test for the skills apparently learned during the training sessions. This test Form appeared to be less difficult overall than the one which had been (randomly) chosen for the pre-test; and with 90% correct performance on the spatial problems of the post-test by the experimental group, the failure to find an overall training effect on the figural analogies test may be at least partially attributable to a ceiling effect. Two surprise follow-up tasks, performed two months after the post-test, were used to further explore these issues.

The first follow-up task was a timed test of the sort taken from the CAT and used in the practice batteries. It should be noted that the practice tests--and hence, the follow-up test--were designed to be more difficult than the actual tests, since most of the test problems were made more complex, through the addition of a spatial transformation (with or without an inversion). This was followed by a protocol task: problems were presented without multiple-choice answer alternatives, and the subject's task was to provide a written protocol of how the third term in the analogy should be transformed so as to generate the fourth. Three problems were included: one which could be solved through rotation or reflection, another which could be viewed as a shading or a number (of elements shaded) problem, and a third which was involved a simple displacement of a figural element, with no spatial transformation of the figure as a whole.

Table III provides the results of the follow-up tasks. First,

Insert Table III about here

training clearly continued to exert an influence on performance, even after a two-month delay interval. The experimental group performed significantly better on the follow-up figural analogy test than did the control group ($t(18)=4.2$, $p<.05$).

Secondly, a look at the type of transformations given in the protocols of the two groups reveals strategic difference between the two groups. The marked differences between the types of transformations chosen by the two groups are clear. Most notably, all of the experimental subjects correctly solved the rotation/reflection problem using rotation or reflection; while fifty percent of the control group--incorrectly--used displacement, and ten percent could not answer the question. Thus, while the control subjects still tended to approach spatial problems in terms of figural displacements, the experimental group had learned to apply precise rotations and reflections to arrive at the correct answer. In addition, results for the shading/number problem indicate that trained subjects were somewhat more likely to both answer correctly and to apply an abstract (number) than a perceptual (shading) figural relation, when given a choice. Finally, the results for the displacement problems are also telling. For this problem, displacement is the correct transformation. Twice as many control subjects as experimental subjects used the displacement relation to answer this problem correctly. Fifty percent of the experimental group (and thirty percent of the control group) incorrectly used spatial rotation, and another twenty percent of the experimental group claimed--again incorrectly--to be able to solve the problem in either of two ways, using displacement or rotation.

Clearly, the experimental subjects in this study attempted to use spatial transformations more than the control subjects did--even when this was inappropriate for problem solution. This tendency may well have attenuated performance on the post-test, which contained fewer spatial problems than did the pre-test. Indeed, after taking the post-test, several experimental subjects reported having persisted in trying to apply complex combinations of rotations and reflections in attempting to answer problems which involved simple displacements. These findings suggest that the training program should be modified to: a) focus somewhat more on "figural" relations; and b) foster a more flexible approach towards trying various possible transformations.

Yet the major thrust of these findings is to demonstrate the fact that training *was* highly successful. Subjects improved their rotation and reflection skills, and learned to apply spatial--and abstract--transformations more often in taking figural analogy tests. The effects of training generalized to improve performance on an entirely different test--the "surface development" test, which involves complex rotations of very different figures. Finally, effects of training could still be observed in improved performance of the experimental group over two months after training had been completed. These results confirm and extend our previous findings on the analogy between "aptitude" and skill in the spatial domain. Moreover, they strongly suggest that nonverbal ability measures such as standardized figural analogy tests should no longer be considered "knowledge-free".

TABLE I

PERCENT CORRECT FOR EXPERIMENTAL AND CONTROL GROUPS

ON PRE- AND POST- FIGURAL ANALOGY AND SURFACE DEVELOPMENT TESTS

	PRE-TEST	POST-TEST
FIGURAL ANALOGY TEST:		
Experimental Group	58.4	83.2
Control Group	60.0	82.0
SURFACE DEVELOPMENT TEST:		
Experimental Group	63.7	74.3
Control Group	63.3	65.3

TABLE II

PERCENT CORRECT FOR EXPERIMENTAL AND CONTROL GROUPS ON SPATIAL AND FIGURAL PROBLEMS ON THE FIGURAL ANALOGY PRE- AND POST-TESTS

	PRE-TEST	POST-TEST
SPATIAL PROBLEMS:		
Experimental Group	50.8	90.0
Control Group	59.2	85.0
FIGURAL PROBLEMS:		
Experimental Group	61.5	77.6
Control Group	63.8	78.8

TABLE III

PERFORMANCE ON FIGURAL ANALOGY FOLLOW-UP TASKS

A. PERCENT CORRECT ON FOLLOW-UP FIGURAL ANALOGY TEST:

Experimental Group	76.8
Control Group	52.4

B. PERCENT OF EACH TYPE OF TRANSFORMATION GIVEN IN PROTOCOLS DURING SOLUTION OF THREE TYPES OF PROBLEMS:

	EXPERIMENTAL GROUP	CONTROL GROUP
ROTATION/REFLECTION PROBLEM:		
Rotation	90	40
Reflection	10	10
Displacement	00	50
No answer	00	10
SHADING/NUMBER PROBLEM:		
Shading	40	40
Number	30	10
Either Shading or Number	30	30
No Answer	00	20
DISPLACEMENT PROBLEM:		
Displacement	30	60
Rotation	50	30
Either Displmt or Rotatn	20	00
No answer	00	10

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