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Relation of Aptitudes to Learning at Different Points in Time During Instruction

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This study examined one possible reason for the lack of consistent findings in aptitude–treatment interaction research, namely, the instability of aptitude–learning relations over time. Four classes of predominantly 10th-grade students were taught an imaginary science over a 4-day period. Achievement measures were obtained each day. Students completed 14 aptitude measures prior to instruction, and 5 additional aptitude scores were obtained from student records. Component scores from a derived principal-components solution to the intercorrelations of the aptitude scores were then correlated with each of the achievement scores. The results indicated that some aptitude–achievement relations were not stable over time and that this instability was exhibited in different aptitudes being required at different points in time during instruction.

The prototypic paradigm in aptitude–treatment interaction (ATI) research is the following: An aptitude construct is measured, two different instructional treatments are used to teach some content and, at the end of the treatment, an outcome measure is obtained. Within each treatment, the outcome measure is regressed onto the aptitude measure. The regression lines are then taken as summary indices of the importance of that aptitude for outcome within each treatment, and the regression weights and treatment means are examined for evidence of ATI.

Implicit in this paradigm is the assumption that the relation of aptitude to outcome is the same at different points in time during instruction. In effect, the regression weights for predicting outcome from aptitude are generalized over the entire duration of the treatment. But there is a body of research suggesting that this assumption may not always be warranted.

Based on two theoretical articles by Ferguson (1954, 1956), a number of studies have shown that the aptitudes required by perceptual–motor learning tasks often shift as learning proceeds on the task (for reviews, see Ferguson, 1965; Fleishman, 1972; Fleishman & Bartlett, 1969). Other studies have extended this finding to more cognitive learning tasks as well (Dunham, Guilford, & Hoepfner, 1968; Frederiksen, 1969; Gagné & Paradise, 1961; Hultsch, Nesselroade, & Plemons, 1976; Labouvie, Frohring, Baltes, & Goulet, 1973; Roberts, King, & Kropp, 1969; Bunderson, Note 1).[1] In general, this research has indicated that (a) the aptitudes required at one "stage of learning" are not always the same aptitudes required at a later stage of learning, or, more commonly, (b) the aptitudes required at one point in time are required to a lesser or greater degree at a later point in time.

If the aptitudes required by instruction shift during the course of learning, then the aptitude–learning relations within each treatment may be misleading: They would reflect the importance of a given aptitude only at the time learning was measured.

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[1] See Labouvie-Vief, Levin, and Urberg (1975) and Alvord (Note 2) for some conflicting findings.

This possible time dependency of aptitude–learning relations would make it difficult to accumulate the results of ATI studies and may be an important reason for some of the conflicting results often reported by ATI researchers.

Although the research on which this argument is based is suggestive, it has used, for the most part, brief laboratory learning tasks where practice, rather than instruction, is the major vehicle for learning. There is little research on the correlation of aptitudes with learning at different points in time during school-based instruction. The purpose of the present study was to determine if the aptitude–learning relations remain stable during the course of learning a complex learning task under conditions typical of school instruction.

Method

Subjects

The 101 students in this study were enrolled in four classes entitled "Change in Society" taught by a male teacher in a California high school. Seventy-six of the students were in the 10th-grade, 19 were in the 11th-grade, and 6 were in the 12th-grade. Fifty-one of the students were male and 50 were female. According to the teacher, the modal student population of the school was white and of lower-middle-class socioeconomic status.

The classes were selected for the study because of the teacher's willingness to participate and his belief that such a project would be appropriate for a "Change in Society" course. The four classes met for the first four periods of the morning school schedule in the same classroom, each class period lasting 50 minutes. The four classes in the study had 25, 28, 23, and 25 students, respectively.

Aptitude Measures

Nineteen aptitude measures were obtained. Nine were from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harman, 1976), four were subtests of the Culture-Fair Intelligence Tests (Scale 2, Form B; Cattell & Cattell, 1960), five were subtests of the Comprehensive Tests of Basic Skills (CTBS; Expanded Edition, Form 5, Level 4; CTB/McGraw-Hill, 1973), and one was developed by the experimenter. A brief description of each test is presented below.

The majority of the aptitude measures included in this study were chosen to reflect the $G_cG_fG_v$ broad ability complex suggested by Snow (1977). This complex is based on Cattell's (1971) distinction between crystallized intelligence (G_c) and fluid intelligence (G_f) and the addition to this complex of a broad visualization ability (G_v) as suggested by Horn (1976). These three aptitude constructs represent the first differentiation of general mental ability (G) in recent hierarchical models of intelligence and summarize many of the more specific aptitudes found in lower strata.

The first nine tests are from the Kit of Factor-Referenced Cognitive Tests, an updated version of the earlier French Kit (French, Ekstrom, & Price, 1963):

Hidden Patterns. This test is a marker for the factor of Flexibility of Closure. The task is to decide whether or not a simple configuration is embedded in a more complex geometric pattern (400 items, 6 minutes).

Vocabulary II. This test is a marker for the factor of Verbal Comprehension. It is a five-choice synonym test (36 items, 8 minutes).

Finding A's. This test is a marker for the factor of Perceptual Speed. The task is to find a few words with the letter *a* embedded in word lists composed of many non-*a* words (200 items, 4 minutes).

Map Memory. This test is a marker for the factor of Visual Memory. The task is to hold in intermediate memory the configuration of 12 aerial road maps presented on a study page so as to identify those maps from among others on a test page (24 items, 12 minutes).

Identical Pictures. This test is also a marker for the factor of Perceptual Speed. The task is to select from five pictorial or geometric objects in a row the one that is identical to a given object at the left of the row (96 items, 3 minutes).

Division. This test is a marker for the factor of Number Facility. The task is to divide two- and three-digit numbers by single-digit numbers (120 items, 4 minutes).

Picture–Number. This test is a marker for the factor of Associative Memory. The task is to hold in intermediate memory 21 pairings of a pictorial object and a two-digit number presented on a study page so as to recall the number when the pictures are presented in a different order on a test page (42 items, 12 minutes).

Card Rotations. This test is a marker for the factor of Spatial Orientation. The task is to determine whether or not irregular shapes are mere rotations (on the plane of the page) of the originally presented shape or are flipped over on their sides (160 items, 6 minutes).

Map Planning. This test is a marker for a factor of Spatial Scanning. The task is to determine which one of several marked intersections is passed on the shortest route between two indicated points on the perimeter of a grid. Blocked paths within the grid make the shortest routes irregular (40 items, 6 minutes).

The next four tests are from the Culture-Fair Intelligence Tests. They are all similar in that they mark a factor usually referred to as Figural Relations or Figural Reasoning, defined as the ability to perceive or educe relations among figural stimuli (Horn, 1977). These tests are thought to measure aspects of fluid intelligence (Cattell, 1971; Snow, 1977):

Series. In this test, the task is to complete a progressive series of figures (12 items, 3 minutes).

Classifications. In this test, the task is to choose one figure from the five presented that is different in some respect from the others (14 items, 4 minutes).

Matrices. In this test, the task is to complete a design or matrix of figures that is incompletely shown (12 items, 3 minutes).

Conditions. In this test, the task is to choose from a set of five figural conditions the one that duplicates a given set of conditions (8 items, 3 minutes).

Table Interpretation. This test was constructed by the experimenter. It is a pretest measuring certain study skills important for learning the curricular materials. The task is to read three simple graphs and tables and answer questions about their content or their interpretation (13 items, 6 minutes).

The last five tests are from the CTBS. The tests are typical standardized achievement tests in reading and arithmetic:

Reading Vocabulary. This is a four-choice synonym test (40 items, 11 minutes).

Reading Comprehension. The task is to answer questions about the content of stories, poems, and letters that had just been read (45 items, 35 minutes).

Arithmetic Computation. The task is to carry out the arithmetic operations of addition, subtraction, multiplication, and division (48 items, 40 minutes).

Arithmetic Concepts. The task is to recognize the appropriate numerical operation or concept to solve a short word problem (25 items, 15 minutes).

Arithmetic Applications. The items in this test are longer word problems and demand more problem solving than in the previous test. The task is to comprehend the problem and carry out the appropriate numerical operation (25 items, 15 minutes).

Instructional Treatment

The instructional treatment used in this study consisted of two phases: a lecture/discussion period involving the class as a whole followed by an individual period in which students read through instructional booklets on their own. For explanatory reasons, the instructional booklets and their curricular contents are described first.

Instructional booklets and their contents. The curricular materials used in this study were a set of four hierarchical learning units describing an imaginary science called *Xenograde Systems* (see Merrill, 1965). Briefly, a Xenograde System consists of two basic parts, a nucleus and orbiting satellites. Alphons are small particles that may reside in the nucleus or the satellites. Under certain conditions, a satellite may collide with the nucleus and exchange one or more alphons. The science of Xenograde Systems deals with the rules and principles by which the location and number of alphons can be determined or predicted.

The version of Xenograde Systems used in this study was developed from several different versions available to the experimenter. Each of the four learning units consisted of a self-paced instructional booklet between four and five pages in length. Each booklet was written in prose accompanied by diagrams, graphs, and tables for explanation. Overall, the format could best be described as a "deductive" delivery, where knowledge and principles were presented and then followed by examples. However, some sections in the latter two learning units were more "inductive," with examples provided first followed by a guided explanation leading to the rule or principle exemplified.

Learning Unit 1 provides an overview of Xenograde Systems. Terms are defined and basic facts on how Xenograde Systems operate are given. The remainder of the unit discusses one part of the system, the alphons within the nucleus. The concept of time is introduced and rules on reading tables of alphon movement are provided.

Unit 2 discusses the second part of a Xenograde System, the three satellites. Rules and procedures for reading graphs of satellite movements are presented. This unit appears not to be as complex as Learning Unit 1, as fewer new terms and concepts are introduced.

Unit 3 discusses satellites in more detail, introducing several more facts and concepts about satellites. The new concepts increase the complexity of the graphs recording satellite movements. A new format of representing satellite movements, tables, is introduced, and several rules for reading the tables are presented. Learning Units 2 and 3 are more related in content than either is to Unit 1.

Unit 4 brings together the concepts of Units 1, 2, and 3 and presents the fully operating Xenograde System. Only two new facts are introduced, but the functioning system is now quite complex. Learners must attend to four or five salient attributes to determine or predict the location and number of alphons within the system.

Lecture/discussion. Since the curricular content to be learned was deemed fairly difficult, a lecture/discussion period, conducted by the experimenter, preceded the reading of each instructional booklet. The lectures lasted from 15 to 25 minutes and essentially covered the material to be learned in the booklets. All student questions were answered; every attempt was made to clarify misunderstandings and help students learn the material.

Achievement Measures

Four, four-distractor multiple-choice achievement tests were developed by the experimenter, one for each of the four learning units. These achievement measures consisted of 18, 14, 16, and 16 test items, respectively. To help ensure that the test items reflected an adequate coverage of the curricular content, the construction of the tests was based on procedures specified by Bloom, Hastings, and Madaus (1971, pp. 117–129). According to Bloom's (1956) taxonomy, the test items measured one of three levels of learning: knowledge, comprehension, or application.

Procedure

The aptitude testing, the teaching of the four learning units, and the achievement testing were carried out on 7 consecutive school days, beginning on a Thursday and ending on the following Friday. Except for the five subtests of the CTBS, whose scores were extracted from student files, the aptitude measures were assembled into three 50-minute test batteries and administered on the first 3 days. The teaching of the learning units and the achievement testing took the next 4 days, with one learning unit and its achievement test being presented each day.

On Thursday, the first day of the study, the teacher explained to each class that they had been selected to participate in a research project being conducted by the local university. Several changes in class assignments, brought about the length of the project, were explained to the students, and then the experimenter was introduced to the class. The experimenter stated that he was interested in educational psychology and, in particular, in how students learn in schools. The general format of the study was then described. Students were told that they would not be graded on their performance during the project. Student questions were answered, and the first aptitude test battery was administered.

Each learning unit was taught initially by a lecture/discussion presentation followed by individual reading of the instructional booklets. The experimenter began each class period with the lecture presentation. Students were encouraged to ask questions during the presentation if they were unclear about the material. Following the presentation, all final student questions were answered and the instructional booklets were distributed. When students completed their study of the booklets, they raised their hands and the experimenter picked up the booklets and distributed the achievement tests on an individual basis. The tests were collected when all students had completed the tests.

Students who were absent for one or more days followed a slightly different procedure. At the beginning of class, these students were identified and seated together. Following the lecture/discussion period for that day and after the instructional booklets had been distributed to the rest of the class, these students were each given the booklet appropriate to their particular level in the instructional sequence. After completing the booklets, questions were answered, and the students were given the appropriate achievement tests. Twelve students, who had been absent on 2 or more days, completed several learning units and the corresponding tests on the same day to catch up with the rest of the class.

Data Analyses

Handling of missing data. Data were not collected for all students on all measures. The major factor contributing to the missing data was student absences due to illnesses, tardies and cuts, and calls from the administration office. The large amount of classroom time necessary to complete the study did not allow additional time for make-up of the measures missed by students (the exception was the make-up procedure for the instructional booklets and achievement tests described earlier). Complete achievement data on all four learning units were obtained for 72 students. Therefore, it was decided to use these 72 cases and estimate any missing aptitude scores by replacing missing values with the mean of that measure based on all available cases, rounded to the nearest integer. Using this procedure, 187 aptitude scores, or 13.7% of the 1,368 total test scores, were estimated.

Statistical analyses. To reduce the number of aptitude scores to a smaller and more manageable number of variables, a principal-components analysis was completed. An incomplete principal-components solution was obtained for the 19 × 19 intercorrelation matrix of aptitude measures with 1s entered in the main diagonal. The criterion for the number of components to extract was Guttman's "weak" lower bound, the number of eigenvalues of the intercorrelation matrix that exceed unity. The initial solution was then rotated orthogonally using the Kaiser normal-varimax procedure. The initial solution extracted five principal components, which were then rotated. The fifth and last component, however, was difficult to interpret. Since this component's eigenvalue was close to unity (1.05), it was decided to obtain an initial solution of four principal components and rotate this solution using the varimax procedure.

Component scores (Mulaik, 1972, p. 322) on each of the four derived aptitude components were then correlated with each of the four achievement tests. Since the procedure for deriving the principal components forces the components, and thus the component scores, to be uncorrelated in the sample, it is possible to determine the relative contribution to learning of each of the four aptitude components through multiple regression.

Results

Descriptive Statistics

The means, standard deviations, reliabilities, and intercorrelations among the aptitude and achievement tests are presented in Table 1. Except for the reliability coefficients, these data were based on a sample of 72 cases, with missing aptitude scores estimated as described previously. The reliability estimates were based on obtained aptitude and achievement data only, with sample sizes ranging from 72 to 100.

Consider the aptitude test data first. In general, the reliabilities were good. The median reliability was approximately .84, and 11 of the 19 reliability estimates fell in the .80s and .90s. The four Culture-Fair subtests had four of the five lowest reliability estimates, but this was a result of their short test length. The manual to the Culture-Fair tests suggests summing the scores for a single index of fluid intelligence (making a more reliable measure), but as will be discussed shortly, there was little empirical justification for doing so with the sample tested. The lowest reliability was for the Map Memory test, where the correlation between the two half-tests was only .29 before correction. Little faith can be put in the aptitude–achievement relations for this aptitude measure.

Several of the aptitude intercorrelations are noteworthy. The four Culture-Fair subtests showed only low-to-moderate intercorrelations in this sample; Classifications, for example, correlated only .09 with Conditions. The low correlations did not justify forming a composite and gave little hope of defining a fluid ability component as anticipated. The two perceptual speed tests correlated only .29, and both tests showed higher correlations with other tests than they did with each other. Similarly, the two memory tests, Picture–Number and Map Memory, correlated only .21, and they too shared more variance with other tests than with each other. This latter result was perhaps reasonable, since both tests were markers for different aptitude factors. But the two perceptual speed tests, Finding A's and Identical Pictures, both marked the same factor and were expected to correlate higher.

Turning to the achievement test data, several points should be noted. First, the reliability estimates for the four achievement measures were all close to .80. Second, learning was good, at least as measured by the achievement tests. The mean proportions correct for the four achievement tests were .70, .74, .74, and .59, respectively. Third, as one might expect, the achievement tests were highly intercorrelated, with correlations ranging from .55 to .77.

Component Structure of the Aptitude Intercorrelations

To reduce the number of aptitude scores to a smaller number of variables, an incomplete principal-components analysis was completed. The initial and derived solutions for the four aptitude components retained, the communalities, and the eigenvalues are presented in Table 2. To facilitate interpretation, only correlations greater than .40 are shown for the derived solution.

The first component was dominated by tests of school achievement, both verbal and numerical. The five subtests of the CTBS and the Vocabulary II and Division tests all loaded highly on this component. The Table Interpretation test also had its highest loading on this component. Since the eight tests loading on this component were all indicative of scholastic achievement yet were diverse in content, Component 1 appeared to reflect *crystallized intelligence* (Cattell, 1971; Snow, 1977) and was labeled as G_c.

The second component was well defined by two spatial tests, Card Rotations and Map Planning, and two of the four Culture-Fair tests, Series and Matrices. Some of the test items in the Series and Matrices tests present figural content in seriated angular positions (i.e., rotated in the plane of the page) and require a response that completes this series or matrix. The other two Culture-Fair tests, Classifications and Conditions, do not have test items where the angular position of a figure or symbol is the critical attribute to identify for a correct response. It was reasonable, then, that Series and Matrices shared considerable variance with the two spatial tests.

It is not uncommon for tests of fluid ability and tests of spatial ability to load on the same component or factor (Snow, 1977). It is likely that similar strategies can be used to solve items on tests of both aptitude constructs. Until more process-oriented research is conducted (e.g., see Hunt, 1974, on fluid ability and Cooper & Shepard, 1978, on spatial ability), it is perhaps best to label components or factors like Component 2 of this study as *fluid-spatial ability* (Snow, in press).

The third component was defined by three tests of three different factors, Hidden Patterns (Flexibility of Closure), Finding A's (Perceptual Speed), and Picture–Number (Associative Memory). The Finding A's test is similar to the Hidden Patterns test in that both tests require one to overcome a complex and distracting visual field. In Finding A's, one must find a few words with the letter *a* embedded in a stimulus field composed of many non-*a* words. In Hidden Patterns, one must find a simple figure embedded in a more complex figure. How Picture–Number fits in is less clear. This test may require a similar cognitive process, since disembedding would facilitate maintaining each paired-associate distinct and separate from other paired associates. Component 3 then, may best be thought of as a *flexibility of closure* component and was tentatively labeled as such.

The fourth component was clearly defined by three tests, Map Memory, Identical Pictures, and Classifications. Again, these three tests mark three separate factors. All three tests are similar in that the response requirement is a same/different decision with respect to figural information held in visual memory. This suggested some sort of visual comparison cognitive process. However, the diversity of tests defining this component made labeling difficult, and the component was referred to merely as *Component 4.*

The reliabilities of the four rotated components were estimated using an adaptation of a procedure suggested by Mulaik (1972, pp. 177–179) for estimating the reliability of unrotated principal components. The component loadings for each component in the derived solution were used to weight the errors of measurement for each of the 19 variables, and the products were summed for each component. This sum was then divided by the appropriate eigenvalue for each rotated component and subtracted from unity. The estimated reliabilities for the four rotated components were .84, .71, .82, and .64, respectively.

Aptitude–Achievement Relations

The simple, corrected, and multiple correlation coefficients between the four sets of component scores and the four achievement scores are presented in Table 3. Consider the multiple correlation coefficients first, which indicated the relation between all components taken together and achievement. The multiple correlations were quite stable over time, showing only a slight decrease for predicting learning on Achievement Test 4. The aptitude components accounted for 34%–41% of the achievement variance in the four learning measures.

Turning to the individual components, a

Table 1
Means, Standard Deviations, Reliabilities, and Intercorrelations for the 19 Aptitude

Measure	*M*	*SD*	1	2	3	4	5	6	7
1. Hidden Patterns	162.68	38.97	92[a]						
2. Vocabulary II	12.53	4.60	12	75[a]					
3. Finding A's	45.72	12.54	51	09	84[a]				
4. Map Memory	17.14	4.38	36	−01	25	45[a]			
5. Identical Pictures	66.83	10.27	27	−23	29	42	84[a]		
6. Division	18.79	10.77	29	26	24	09	07	92[a]	
7. Series	8.08	1.67	25	14	08	21	23	08	49[b]
8. Classifications	8.06	1.82	08	19	22	20	37	06	22
9. Matrices	9.07	2.20	34	15	22	22	20	21	44
10. Conditions	5.90	1.64	33	26	25	15	15	17	16
11. Picture–Number	15.51	7.39	35	18	46	21	13	27	00
12. Card Rotations	87.64	33.25	36	11	21	18	32	12	60
13. Map Planning	17.85	4.74	31	−02	25	11	33	24	40
14. Table Interpretation	10.15	2.09	40	27	28	20	15	36	15
15. CTBS Vocabulary	22.21	7.13	20	62	10	19	−06	37	12
16. CTBS Comprehension	24.89	7.77	31	59	33	18	10	43	15
17. CTBS Computation	27.69	9.53	28	43	28	21	17	59	20
18. CTBS Concepts	16.49	5.32	33	44	26	17	22	48	22
19. CTBS Applications	10.11	4.23	34	53	15	11	−06	46	12
20. Achievement 1	13.43	3.50	32	31	26	35	08	28	28
21. Achievement 2	11.07	2.24	37	25	39	29	14	45	09
22. Achievement 3	12.54	3.03	40	17	18	28	18	31	36
23. Achievement 4	9.49	3.44	33	31	12	32	06	32	36

Note. CTBS = Comprehensive Tests of Basic Skills. Decimals have been omitted from the reliabilities and tically significant at the .05 and .01 levels, respectively. [a] Part 1 – Part 2 correlations stepped up by the different picture emerged. Except for the G_c component, whose contribution to achievement was fairly stable over time, two of the other three components related differentially to learning. The fluid-spatial component showed a decrease in correlation at Time 2 and an increase in correlation at Time 3. The flexibility of closure component showed an opposite pattern, with an increase in correlation at Time 2 and a decrease in correlation over the latter two time points. Component 4 showed little relation to learning at any time during instruction.

It is noteworthy that the two differential aptitude–learning relations described above are not trivial. The smallest and largest corrected correlations for the fluid-spatial component were .18 and .54; for the flexibility of closure component, the smallest and largest correlations were .14 and .53. Although the dominance of G_c was apparent, both the fluid-spatial and flexibility of closure components exhibited at least one correlation close in magnitude to that exhibited by G_c.

When previous achievement was entered as a predictor alongside the four component scores, several details were added to the results presented earlier. The beta weights and multiple regression coefficients for each of the four multiple regressions of achievement onto the components and previous achievement are presented in Table 4. Adding previous achievement as an independent variable allowed it to pick up weight as a predictor and decreased the weight given to the component scores.

As one might expect, previous achievement (primarily immediately preceding achievement) predicted subsequent achievement more and more as learning proceeded on the task. The beta weights for Achievement (Ach) 1 predicting Ach 2, Ach 2 predicting Ach 3, and Ach 3 predicting Ach 4 were .43, .45, and .54, respectively. By Time 4, the aptitude components contributed little to the prediction of learning. Notice, however, that even though the beta weights for the components generally decreased over time, the importance of the

Measures and the 4 Achievement Measures

8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
49[b]															
28	67[b]														
09	31	61[b]													
08	24	19	80[a]												
18	40	30	29	90[a]											
10	29	18	26	59	71[a]										
09	45	35	35	38	32	70[b]									
16	16	34	25	16	14	45	90[c]								
25	28	43	32	26	18	49	80	90[c]							
07	14	33	39	26	33	40	58	64	93[c]						
18	27	42	34	28	24	44	58	67	77	84[c]					
15	23	28	34	18	29	52	72	70	73	69	84[c]				
00	27	34	27	39	25	44	51	54	49	55	53	83[b]			
02	28	23	26	23	25	50	41	46	54	55	51	64	76[b]		
18	46	35	16	44	26	50	48	41	37	51	46	55	62	80[b]	
14	30	20	15	39	28	40	44	38	43	49	46	61	61	77	76[b]

intercorrelations. Reliabilities are given on the main diagonal. Correlations greater than .23 and .30 are statis-
Spearman-Brown formula. [b] Coefficient alpha. [c] Obtained from test manual.

Table 2
Initial and Derived Component Solutions, Communalities (h^2), and Eigenvalues for the Matrix of Aptitude Intercorrelations

	Initial solution					Derived solution			
Test	1	2	3	4	h^2	1	2	3	4
Hidden Patterns	57	34	−30	−14	55			64	
Vocabulary II	53	−51	25	20	64	78			
Finding A's	47	31	−54	01	61			71	
Map Memory	35	38	−27	39	49				60
Identical Pictures	28	63	−19	32	62				63
Division	57	−19	−17	−20	44	51			
Series	38	46	60	00	72		80		
Classifications	30	25	12	71	67				77
Matrices	50	37	26	04	45		57		
Conditions	53	04	04	03	29				
Picture-Number	52	09	−43	−22	52			67	
Card Rotations	52	52	−38	−24	75		83		
Map Planning	48	45	20	−41	63		71		
Table Interpretation	68	03	−02	−19	49	47			
CTBS Vocabulary	71	−47	13	17	77	87			
CTBS Comprehension	81	−33	02	18	80	85			
CTBS Computation	78	−26	−08	−10	70	73			
CTBS Concepts	79	−21	−01	04	68	75			
CTBS Application	77	−40	05	−06	77	84			
Eigenvalue	6.36	2.54	1.42	1.24					

Note. CTBS = Comprehensive Tests of Basic Skills. Decimals have been omitted from the correlations. For interpretive purposes, only correlations greater than .40 are shown for the derived solution.

flexibility of closure component at Time 2 and the fluid-spatial component at Time 3 remained, supporting the results presented earlier.

At the suggestion of a reviewer, an additional analysis was performed as a check on the validity of the reported aptitude-achievement correlations. The reviewer suggested that component scores on the first two unrotated components be correlated with each of the four achievement scores. The first two unrotated components, according to the reviewer, represented G (general mental ability) and the profile difference $G_{fv} - G_c$. By correlating the two unrotated components with achievement one would be able to check whether interpretation should rest on G alone or whether there was value in basing interpretation on the rotated components of G_c and G_{fv}.

When this analysis was performed, the correlations between G (unrotated Component 1) and the achievement measures were .62, .61, .60, and .56; the correlations between the profile difference $G_{fv} - G_c$ (unrotated Component 2) and the achievement measures were −.05, −.05, .11, and .01. At face value, this suggested that G_c and G_{fv}, the rotated components, were spurious, and interpretation should have rested on G alone. However, the reader should keep several points in mind when evaluating the data presented previously.

First, by computing component scores on the profile difference $G_{fv} - G_c$, a restriction in range occurred, since students high on both G_{fv} and G_c and students low on both G_{fv} and G_c received approximately the same score. This restriction in range may have attenuated correlations with other variables. Second, note that the test variable of Identical Pictures received the most weight (.63) of any test in computing the G_{fv} pole of the profile difference $G_{fv} - G_c$ component score. Yet Identical Pictures did not define G_{fv} in the rotated solution and by itself correlated negligibly with achievement. Third, component scores on the profile difference $G_{fv} - G_c$ did not represent entirely the same construct as component scores on the rotated components of G_c and G_{fv}. Having a high positive component score on the profile dif-

Table 3
Simple, Corrected, and Multiple Correlation Coefficients Between the Aptitude Component Scores and the Achievement (Ach) Scores

Component	Achievement measure			
	Ach 1	Ach 2	Ach 3	Ach 4
1	.51*	.46*	.42*	.44*
	(.61)	(.58)	(.51)	(.56)
2	.27	.13	.41*	.35*
	(.35)	(.18)	(.54)	(.48)
3	.25	.42*	.17	−.11
	(.30)	(.53)	(.21)	(.14)
4	.06	.05	.16	.10
	(.08)	(.07)	(.22)	(.14)
R	.63*	.64*	.63*	.58*

Note. Numbers in parentheses are correlation coefficients corrected for attenuation. Since the component scores are uncorrelated in the sample, the simple correlation coefficients are also the standardized partial regression coefficients for predicting achievement from the four aptitude components.
* $p < .01$.

ference $G_{fv} - G_c$ meant that an individual was high on G_{fv} relative to G_c and having a low negative component score meant an individual was high on G_c relative to G_{fv}. This construct was different than being high or low on G_{fv} alone and being high or low on G_c alone, although the two constructs were correlated (as they must be). Component scores on the profile difference $G_{fv} - G_c$ correlated −.61 with component scores on G_c (rotated Component 1) and .59 with component scores on G_{fv} (rotated Component 2), indicating that they shared approximately 36% of their variability.

Table 4
Standardized Partial Regression Coefficients and Multiple Correlation Coefficients for Predicting Achievement (Ach) From the Aptitude Components and Previous Achievement

Independent measure	Dependent measure			
	Ach 1	Ach 2	Ach 3	Ach 4
Component				
1	.51*	.25	.16	.04
2	.27	.02	.33*	.05
3	.25	.31*	−.04	−.10
4	.06	.02	.14	−.01
Achievement				
1		.43*	.09	.21
2			.45*	.16
3				.54*
R	.63*	.72*	.74*	.81*

* $p < .01$.

Discussion

The purpose of this research was to determine if unstable aptitude–learning relations would occur during the course of school learning. The results of this study suggested that some aptitude–learning relations are not stable over time and that this instability is exhibited in different aptitudes being required at different points in time during instruction. These findings supported most of the previous research examining aptitude correlates at different stages of learning and did not support the assumption made in ATI research that aptitudes relate equally to learning for the duration of a treatment.

Although the studies that have addressed the question of aptitude requirement shifts, including the present research, are suggestive, they are few in number and have yet to establish whether unstable aptitude–learning relations are a phenomena broad enough to warrant consideration in ATI research. Good ATI studies are difficult enough to complete without complicating matters. But the importance of the results of this study cannot be denied. If some aptitude–learning relations are not stable over time, then the time dependency of such relations must be recognized if consistent results are to be obtained in ATI research. This would entail collecting learning data at different points in time and performing a series of sequential statistical analyses. This may not be a bad suggestion for all instructional research. Researchers have usually employed outcome measures at the *end* of instruction to quantify learning while ignoring changes that occur *during* learning. But it is the process of change, from ignorance to competence, which should be the major focus of instructional psychology.

At a general level, one can speculate that differential aptitude–learning relations would be expected simply from the very nature of learning itself. Implicit in all theories of learning is that learning extends in time and that learners change during the course of learning. Glaser (1976), for example, has described four kinds of changes occurring between an early stage of competence characteristic of the novice and a later stage characteristic of the expert:

> (a) Variable, awkward, and crude performance changes to performance that is consistent, relatively fast, and precise. Unitary acts change into larger response integrations and overall strategies. (b) The contexts of performance change from simple stimulus patterns with a great deal of clarity to complex patterns in which information must be abstracted from a context of events that are not all relevant. (c) Performance becomes increasingly symbolic, covert, and automatic. The learner responds increasingly to internal representations of an event, to internalized standards, and to internalized strategies for thinking and problem solving. (d) The behavior of the competent individual becomes increasingly self-sustaining in terms of skillful employment of the rules when they are applicable and subtle bending of the rules in appropriate situations. (p. 9)

It is clear from Glaser's description that early forms of learning are quite different from later forms of learning. It is reasonable to suppose that shifts in aptitude requirements may underlie the transition from novice behavior to expert behavior. What is not clear, however, is the form that such shifts might take. One possibility is suggested here.

Suppose we view any instructional treatment as consisting of two sources of aptitude requirements, those associated with the method of instruction and those associated with the content of instruction. Then it is possible that each source would demand a certain set of aptitudes. In particular, the hypothesis is offered here that G_c is the aptitude required primarily by the *method* of instruction, whereas more specific aptitude constructs, like fluid-spatial ability and flexibility of closure, are the aptitudes required primarily by the *content* of instruction. These two sources are often confounded in ATI research (Fleishman & Bartlett, 1969).

To develop this hypothesis, it is necessary to briefly examine the nature of the abilities suggested previously. According to Snow (in press), G_c represents

> the long term accumulation of knowledge and skills, organized into functional cognitive systems by prior learning, that are in some sense crystallized as units for use in future learning. Since these are products of past education, and since education is in large part accumulative, transfer relations between past and future learning is assured. The transfer need not be primarily of specific knowledge but rather of organized academic learning skills. Thus G_c may represent prior assemblies of performance processes retrieved as a system and applied anew in instructional situations not unlike those experienced in the past.

If this description of G_c is accurate, and G_c transfers not specific knowledge but rather general learning to learn skills, then G_c in some sense transcends the particular content of instruction. It would represent a general set of skills to handle how the instruction was presented, to the extent that the instruction was representative of instruction students experienced in the past. It would be expected that G_c would exhibit a fairly stable relation to learning for the duration of a treatment as long as there were no drastic changes in the method of instruction. Such a trend was observed in the present research.

Now consider the other two components identified in this study, fluid-spatial ability and flexibility of closure. According to Carroll (1976), spatial ability is a short-term visual memory process whereby a configuration is mentally rotated. Flexibility of closure is also a short-term visual memory process, but rather than rotate a configuration, the configuration is imaged in relation to its surrounding context.

Considering the relatively specific cognitive processes apparently involved in these aptitude constructs, it is difficult to imagine how they could be required in any major way to be a method of instruction. Very few instructional methods would appear to require students to mentally rotate some configuration, for example. But it is reasonable to assume that such processes could be required, at certain times, by the content of a learning task. If this reasoning is correct, it would be expected that such requirements might change during the course of learning, depending on the content that is being learned at a given time. Certain aptitude–learning relations would be expected to demonstrate instability over time, much like the fluid-spatial and flexibility of closure components of this study.

This hypothesis suggests that the reason some aptitude–learning relations demonstrate a time dependency is that they reflect mainly the content requirements of instruction. Other aptitudes, reflecting the method requirements of instruction, would be expected to demonstrate relatively stable relations to learning. It is possible that this interpretation accounts for the fact that broad aptitudes like G_c usually demonstrate more consistent ATI results than more specialized aptitudes (Cronbach & Snow, 1977, especially chap. 9).

Reference Notes

1. Bunderson, C. *Transfer of mental abilities at different stages of practice in the solution of concept problems* (Research Bulletin 67-20). Princeton, N.J.: Educational Testing Service, 1967.
2. Alvord, R. *Learning and transfer in a concept-attainment task: A study of individual differences* (Tech. Rep. No. 4: Project on individual differences in learning ability as a function of instructional variables). Palo Alto, Calif.: Stanford University, February 1969.

References

Bloom, B. (Ed.). *Taxonomy of educational objectives, Handbook I: Cognitive domain.* New York: McKay, 1956.

Bloom, B., Hastings, J., & Madaus, G. *Handbook on formative and summative evaluation of student learning.* New York: McGraw-Hill, 1971.

Carroll, J. Psychometric tests as cognitive tasks: A new "structure of intellect." In L. Resnick (Ed.), *The nature of intelligence.* Hillsdale, N.J.: Erlbaum, 1976.

Cattell, R. *Abilities: Their structure, growth, and action.* Boston: Houghton Mifflin, 1971.

Cattell, R., & Cattell, A. *Culture Fair Intelligence Test, Scale B.* Champaign, Ill.: Institute for Personality and Ability Testing, 1960.

Cooper, L., & Shepard, R. Transformations on representations of objects in space. In E. Carterette & M. Friedman (Eds.), *Handbook of perception* (Vol. 8). New York: Academic Press, 1978.

Cronbach, L., & Snow, R. *Aptitudes and instructional methods: A handbook for research on interactions.* New York: Irvington, 1977.

CTB/McGraw-Hill. *Comprehensive Tests of Basic Skills.* Monterey, Calif.: Author, 1973.

Dunham, J., Guilford, J., & Hoepfner, R. Multivariate approaches to discovering the intellectual components of concept learning. *Psychological Review,* 1968, *75,* 206–221.

Ekstrom, R., French, J., & Harman, J. *Kit of factor-referenced cognitive tests.* Princeton, N.J.: Educational Testing Service, 1976.

Ferguson, G. On learning and human ability. *Canadian Journal of Psychology,* 1954, *8,* 95–112.

Ferguson, G. On transfer and the abilities of man. *Canadian Journal of Psychology,* 1956, *10,* 121–131.

Ferguson, G. Human abilities. *Annual Review of Psychology,* 1965, *16,* 39–62.

Fleishman, E. On the relation between abilities, learning, and human experience. *American Psychologist,* 1972, *27,* 1017–1032.

Fleishman, E., & Bartlett, C. Human abilities. *Annual Review of Psychology,* 1969, *20,* 349–379.

Frederiksen, C. Abilities, transfer, and information retrieval in verbal learning. *Multivariate Behavioral Research Monographs,* 1969 (No. 69-2).

French, J., Ekstrom, R., & Price, L. *Kit of reference tests for cognitive factors.* Princeton, N.J.: Educational Testing Service, 1963.

Gagné, R., & Paradise, N. Abilities and learning sets in knowledge acquisition. *Psychological Monographs,* 1961, *75*(14, Whole No. 518).

Glaser, R. Components of a psychology of instruction: Toward a science of design. *Review of Educational Research,* 1976, *46,* 1–24.

Horn, J. Human abilities: A review of research and theory in the early 1970's. *Annual Review of Psychology,* 1976, *27,* 437–485.

Horn, J. Personality and ability theory. In R. Cattell & R. Dreger (Eds.), *Handbook of modern personality theory.* Washington, D.C.: Hemisphere, 1977.

Hultsch, D., Nesselroade, J., & Plemons, J. Learning-ability relations in adulthood. *Human Development,* 1976, *19,* 234–247.

Hunt, E. Quote the raven? Nevermore! In L. Gregg (Ed.), *Knowledge and cognition.* Hillsdale, N.J.: Erlbaum, 1974.

Labouvie, G., Frohring, W., Baltes, P., & Goulet, L. Changing relationship between recall performance and abilities as a function of stage of learning and timing of recall. *Journal of Educational Psychology,* 1973, *64,* 191–198.

Labouvie-Vief, G. Levin, J., & Urberg, K. The relationship between selected cognitive abilities and learning: A second look. *Journal of Educational Psychology,* 1975, *67,* 558–569.

Merrill, M. Correction and review on successive parts in learning a hierarchical task. *Journal of Educational Psychology,* 1965, *56,* 225–234.

Mulaik, S. *The foundation of factor analysis.* New York: McGraw-Hill, 1972.

Roberts, D., King, F., & Kropp, R. An empirical investigation of Ferguson's theory of human abilities. *Canadian Journal of Psychology,* 1969, *23,* 254–267.

Snow, R. Learning and individual differences. *Review of Research in Education,* 1977, *4,* 50–105.

Snow, R. Aptitude processes. In R. Snow, P. Federico, & W. Montague (Eds.), *Aptitude, learning and instruction: Cognitive process analysis.* Hillsdale, N.J.: Erlbaum, in press.

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