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ABSTRACT

To ascertain changes in cognitive correlates of learning as students advance through hierarchical instruction, 24 individual difference measures were obtained from 166 Navy trainees who had completed a computer-managed course in electricity and electronics. Principal component analysis and varimax rotation were computed for cognitive characteristics, producing factor scores that were used in multiple regression analyses to predict achievement in 11 modules of instruction. During acquisition of course content, the cognitive components sampled shifted noticeably in importance throughout the curriculum. The results have implications for research on aptitude treatment interaction (ATI), transition from novice to expert, crystallized and fluid intelligence, task demands of instruction, and computer managed mastery learning. (Author/LMM)

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COMPUTER-MANAGED INSTRUCTION: STABILITY OF COGNITIVE COMPONENTS

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FOREWORD

This research was performed under exploratory development work unit RF63-522-801-013-03.04 (Testing Strategies for Operational Computer-based Training) under the sponsorship of the Chief of Naval Material (Office of Naval Technology). The general goal of this work unit is to evaluate the impact of different computer-based testing strategies for operational training.

The results of this study are primarily intended for the Department of Defense training and testing research and development community.

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SUMMARY

Problem

Very little research has examined the nature of the relationship of aptitudes to achievement as students progress through computer-managed instruction (CMI). Data are required to help establish whether aptitude-achievement relationships are stable enough to warrant consideration by instructional researchers and developers as well as training managers.

Objective

The objective of this research was to determine the nature and extent of changes in the cognitive correlates of learning as students advance through hierarchical modules of CMI.

Approach

Twenty-four measures of cognitive attributes were obtained from 166 Navy trainees as they completed a computer-managed mastery course in electricity and electronics. Principal component analysis and varimax rotation were computed for student individual difference measures, producing factor scores that were used in multiple regression analyses to predict achievement in 11 modules of instruction.

Results

Within limits, student proficiency throughout the modules could be predicted by using measures of these cognitive components. Changes in the proportion of variance in student performance throughout the modules accounted for by certain cognitive components represented shifts in their emphasis during the process of acquiring the course content. These shifts in predictor patterns of cognitive components appeared to be related to whether a module required students to remember or use facts, concepts, principles, and/or rules. Different cognitive components seemed to contribute more or less to student achievement at distinct modules or stages of learning.

Discussion

Considerable changes occurred in the cognitive predictors of achievement as students progressed through the sequential modules of instruction. During the acquisition of course content, the importance of the cognitive components sampled shifted noticeably throughout the curriculum. Different components appeared to contribute variance at earlier and at later phases of mastery. After progressing through hierarachical modules, individual differences in learning depend more on certain cognitive components and less on others than they did when beginning to acquire the course contents. The use of specific components is minimal in early stages of training, but prerequisite for later acquisition. Yet, other cognitive components may remain rather unchanging during the mastery of the complete curriculum.

Conclusions and Recommendations

It was highly likely that the cognitive processing involved in the initial phases of learning differed from the processing at terminal phases of acquisition. This suggested the requirement for protocol analyses of the cognitive processing involved in early,

intermediary, and later phases of learning. It must be determined whether particular aptitudes that contribute to learning at distinct stages reflect the presence of prerequisite cognitive competencies, schemata, knowledge, and learning sets required to acquire the subject matter at particular phases of mastery. The instability of the relationships of some cognitive components across distinct stages of learning suggested the importance of concentrating on the process of change from ignorance to competence.

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INTRODUCTION

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Several studies have shown that aptitudes demanded by perceptual-motor tasks usually shift as students improve their performance (Ferguson, 1965; Fleishman, 1972; Fleishman & Bartlett, 1969). Other investigations have extended this result to more cognitive learning tasks (Bunderson, 1967; Dunham, Guilford, & Hoepfner, 1968; Frederiksen, 1969; Gagne & Paradise, 1961; Hultsch, Nesselroade, & Plemons, 1976; Labouvie, Frohring, Baltes, & Goulet, 1973; Roberts, King, & Kropp, 1969). If aptitudes required at one stage of mastery are not always similar to those needed at later stages, then some established aptitude-learning relationships may be misleading for certain instructional treatments. They would represent the importance of specific aptitudes only at those specific times when achievement was assessed. This could make the results of aptitude-treatment-interaction (ATI) studies (Cronbach & Snow, 1977) more difficult to interpret and contribute to the conflicting findings of many of these investigations. Most of the research upon which this speculation is based involved the practice of laboratory learning tasks--not academic instruction.

Very little research has examined the nature of the relationship of aptitudes to achievement as students progress through scholastic instruction. The results of Burns' study (1980) suggested that certain aptitude-learning relationships are not stable throughout instruction. These findings did not support an important assumption made in ATI research--that the relationship of aptitudes to achievement is stable during the course of learning for a specific instructional treatment. The curricular materials used in the Burns' investigation were hierarchical learning units for an imaginary science, which were taught and tested within a 4-day time frame. Neither the subject matter nor the duration of learning appeared to represent with sufficient fidelity real-world, school-based, instructional situations. Consequently, the results of this study are at best suggestive.

Additional data are required to help establish whether aptitude-achievement relationships are stable enough to warrant consideration by ATI researchers.

Objective

The objective of this research was to determine the nature and extent of changes in the cognitive correlates of learning as students advance through hierarchical modules of computer-managed instruction (CMI).

APPROACH

Subjects

The subjects were 340 individuals who graduated from recruit training at the Naval Training Center (NTC), San Diego and were scheduled for instruction at the Basic Electricity and Electronics (BE/E) School at NTC San Diego. Before beginning the BE/E orientation, the subjects were administered 12 tests--6 designed to measure their cognitive styles; and 6, their abilities. Test data were discarded for 20 subjects who did not follow directions and/or completed less than 9 of the 12 tests and 40 who did not graduate (35 for academic and 5 for nonacademic reasons). Thus, test data were available for 280 BE/E graduates.

Aptitudes of all individuals entering the Navy are measured by their scores on the 12 subtests of the Armed Services Vocational Aptitude Battery (ASVAB). However, the ASVAB scores for 108 subjects of this study were either incomplete or missing. For 6 additional graduates, the module test score data usually maintained by the CMI system for all BE/E students were missing or incomplete. Thus, the final sample consisted of 166 BE/E graduates.

Cognitive Characteristic Measures

The three types of cognitive characteristic measures used in the study were tests of cognitive styles, abilities, and aptitudes. Cognitive styles are the dominant modes of information processing that individuals typically employ when perceiving, learning, or problem solving. Abilities are the intellectual capabilities of individuals that are general and pervasive to the performance of many tasks. Aptitudes are indices used to select personnel to perform tasks that demand specific skills and to find the right person for a certain job or school.

The six tests designed to measure cognitive styles were chosen because of their implications for adaptive instruction (Kogan, 1971); and the six tests designed to measure abilities, because they represent various types of information-processing tasks (Carroll, 1974, 1976) and are relevant to the BE/E subject matter. The ASVAB subtests were selected as measures of aptitudes because they are typically readily available for Navy personnel and the basis for assigning personnel to different Navy schools. Also, the ability and aptitude measures were included in the investigation to reflect crystallized (G_c) and fluid (G_f) intelligence (Cattell, 1971; Horn, 1976; Snow, 1980; Cronbach & Snow, 1977). Tests that are allegedly indicative of traditional educational achievement (i.e., verbal, quantitative, and reasoning abilities) usually index G_c. Tests that are allegedly indicative of adaptation in novel learning situations (i.e., abstract, nonverbal, spatial, and figural reasoning abilities) usually index G_f. All of the tests are (1) relatively independent, (2) moderate to high in reliability, (3) paper and pencil in nature, and (4) fairly short in duration.

Table 1 presents the 24 cognitive characteristic tests used in this study.

Instructional Treatment

The instructional treatment consisted of the first 11 modules of the BE/E school curriculum, course file 69. This involved CMI to implement the mastery learning of the subject matter of the modules.

Computer-managed Instruction

In CMI, students self-study and self-pace themselves through off-line lesson modules (i.e., they do not interact directly with the system while learning). This differs from computer-assisted instruction where students interact in real time with course contents and tests stored in the computer via on-line terminals. Also in CMI, the computer via its distributed terminals (1) scores criterion-referenced multiple-choice tests students take off-line, (2) interprets test results and provides the students with feedback regarding their performance, (3) advises students to learn the next or alternative lesson or to remediate mastery modules, and (4) manages student records, instructional resources, and administrative data (Baker, 1978; Orlansky & String, 1979).

Table 1

Cognitive Characteristic Measures

Cognitive Characteristic	Abbreviation	Description	Measurement Instrument
		Cognitive Styles	
Field independence vs. field dependence	FILDINDP	Analytical vs. global orientation	Hidden figures test, part I (Ekstrom, French, Harman, & Derman, 1976)
Conceptualizing style	CONCSTYL	Span of conceptual category	Clayton-Jackson object sorting test (Clayton & Jackson, 1961)
Reflectiveness-impulsiveness	REFLIMPL	Deliberation vs. impulse	Impulsivity subscale from personality research test, form E (Jackson, 1974)
Tolerance of ambiguity	TOLRAMBQ	Inclined to accept complex issues	Tolerance of ambiguity scale from self-other test, form C (Rydell & Rosen, 1966)
Category width	CATEWIDH	Consistency of cognitive range	Category width scale (Pettigrew, 1958)
Cognitive complexity	COGCOMPX	Multidimensional perceptions of the environment	Group version of role construct repertory test (Bieri, Atkins, Briar, Leaman, Miller, & Tripodi, 1966)
		Abilities	
Verbal comprehension	VERBCOMP	Understanding the English language	Vocabulary test, part I (Ekstrom et al., 1976)
General reasoning	GENLREAS	Solving specific problems	Arithmetic aptitude test, part I (Ekstrom et al., 1976)
Associational fluency	ASSOFLUN	Producing similar words rapidly	Controlled associations test, part I (Ekstrom et al., 1976)
Logical reasoning	LOGIREAS	Deducing from premise to conclusion	Nonsense syllogisms test, part I (Ekstrom et al., 1976)
Induction	INDUCTON	Forming hypotheses to fit certain facts	Figure classification test, part I (Ekstrom et al., 1976)
Ideational fluency	IDEAFLUN	Generating ideas about a specific type	Topics test, part I (Ekstrom et al., 1976)
		Aptitudes	
General information	GENLINFO	Recognizing factual information	General information subtest, ASVAB
Numerical operations	NUMROPER	Completing arithmetic operations	Numerical operations subtest, ASVAB
Attention to detail	ATTNDETL	Finding an important detail	Attention to detail subtest, ASVAB
Word knowledge	WORDKNOL	Comprehending written and spoken language	Word knowledge subtest, ASVAB
Arithmetic reasoning	ARTHREAS	Solving arithmetic word problems	Arithmetic reasoning subtest, ASVAB
Space perception	SPACPERC	Visualizing objects in space	Space perception subtest, ASVAB
Mathematics knowledge	MATHKNOL	Employing mathematical relationships	Mathematics knowledge subtest, ASVAB
Electronics information	ELECINFO	Using electronics relationships	Electronics information subtest, ASVAB
Mechanical comprehension	MECHCOMP	Reasoning with mechanical concepts	Mechanical comprehension test, ASVAB
General science	GENLSCIE	Perceiving relationships between scientific concepts	General science subtest, ASVAB
Shop information	SHOPINFO	Knowing shop tools	Shop information subtest, ASVAB
Automotive information	AUTOINFO	Knowing automotive functions	Automotive information subtest, ASVAB

Mastery Learning

Mastery learning has many major features (Block, 1974; Bloom, 1974, 1976):

1. Mastery is explained relative to the specific instructional objectives every student is required to achieve.

2. The instruction itself is structured into clearly defined learning units or modules.

3. Every student must master each module completely before proceeding to the next module.

4. A diagnostic objective-referenced test is administered to every student at the end of each module to provide feedback on the adequacy of the student's learning.

5. Based upon the diagnostic information, a student's original instruction is remediated and/or supplemented so that he/she can successfully master the module.

6. Time to complete each module is used as the means of individualizing instruction and thus promoting mastery of the material.

Module Booklets

The individualized learning materials used in this study were a set of 11 hierarchical learning modules designed and developed to teach basic facts, concepts, principles, and rules regarding electricity and electronics. These modules were selected for this research since students from all electronics-related Navy ratings must master them successfully before proceeding to more specialized training. Each module was presented as a self-study booklet consisting of three to seven lessons.

To learn a lesson within a booklet, students could choose, based upon their experience and preference, a narrative presentation, programmed instruction, and/or straightforward summary. These alternative lesson training treatments could be complemented by enrichment material or the instructor if the students so desired. Students were encouraged to use as many of the instructional resources as necessary to master the module material. Many schematics, circuit diagrams, photographs of meters, and algebraic expressions supplemented the descriptive prose in each of the booklets. Typically, the presentation of the many facts, concepts, principles, and rules was followed by appropriate examples.

Subject-matter Content

The subject-matter content of the 11 modules' lessons was as follows:

1. Electrical current--electricity and the electron, electron movement, current flow, measurement of current, and the ammeter.

2. Voltage--electromotive force from chemical action, magnetism, electromagnetic induction, AC voltage, uses of AC and DC, and measuring voltage.

3. Resistance--characteristics of resistance, resistors, resistor values, and ohmmeters.

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4. Current and voltage in series circuits--measuring current and voltage in a series circuit and using the multimeter as a voltmeter.

5. Relationships of current, voltage, and resistance--voltage, resistance, and current, Ohm's law formula, power, internal resistance, and troubleshooting series circuits.

6. Parallel circuits--rules for voltage and current, rules for resistance and power, variational analysis, and troubleshooting parallel circuits.

7. Combination circuits and voltage dividers--solving complex circuits, voltage reference, and voltage dividers.

8. Induction--electromagnetism, inductors and flux density, inducing voltage, and inductance and induction.

9. Relationships of current, counter electromotive force, and voltage in inductance-resistance circuits--rise and decay of current and voltage, inductance-resistance time constant, using the universal time constant chart, inductive reactance, relationships in inductive circuits, and phase relationships.

10. Transformers--transformer construction, transformer theory and operation, turns and voltage ratios, power and current, transformer efficiency, and semiconductor rectifiers.

11. Capacitance--the capacitor, theory of capacitance, total capacitance, resistance-capacitance time constant, capacitive reactance, phase and power relationhips, and capacity design considerations.

Achievement Measures

The achievement test score for each of these sequential modules was the number of items correct on a student's first attempt at taking a mastery quiz. These end-of-module tests consisted of from 10 to 45 four-alternative multiple-choice items that were congruent with instructional objectives. The number of contact hours each student required to master the instructional material of each module was retrieved from the CMI system. The means and standard deviations (given in parentheses) of the times, in hours, required by the students to complete the 11 modules were 5.56 (3.59), 6.93 (3.45), 6.34 (2.77), 8.05 (4.68), 14.27 (7.72), 9.18 (4.89), 19.83 (9.60), 6.43 (3.41), 9.58 (4.51), 6.98 (4.06), and 8.55 (4.08), respectively. The average total number of contact hours for students to complete this curriculum was 101.70, which represents 16.95 course days of 6 hours of instruction each.

Statistical Analyses

A principal components analysis with no iterations (Hotelling, 1933) was computed for the 24 x 24 intercorrelation matrix of the cognitive characteristics to obtain a smaller and more manageable number of variables. The minimum eigenvalue criterion was employed to establish the number of significant principal components to be rotated for the terminal solution (i.e., only components with eigenvalues greater than or equal to one were retained. Kaiser's (1958) varimax procedure was used to rotate orthogonally the initial component solution. Derived component scores were computed for subjects and used as predictors in performing 11 multiple regression analyses. These determined the amount of variance that the cognitive components accounted for in the module achievement scores; that is, the terminal rotated solution also yielded orthogonal dimensions resulting in independent component scores. Consequently, it was feasible to ascertain the relative contributions of the cognitive components to module achievement.

RESULTS

Descriptive Statistics

The means, standard deviations, and intercorrelations for the 24 cognitive characteristics and 11 module achievement scores are presented in Table 2.[1] Some of these correlations are noteworthy. The diagonal correlations between successive module scores did not increase monotonically, which suggests that the performance in each module did not correlate the strongest with the performance in the modules immediately preceding or following it. As the sequential separation between modules increased (i.e., moving across the rows of the matrix to the right or down the columns), the correlations did not decrease. This implies that the remoteness of a module from another module did not necessarily lessen the relationship between them. Most of the cognitive styles measures were not significantly correlated with ability and aptitude measures. The primary exception was FILDINDP, which was related to GENLREAS, ASSOFLUN, MATHKNOL, ELECINFO, and MECHCOMP. Some of the strongest relationships existed among measures of WORDKNOL, ELECINFO, MECHCOMP, GENSCIE, and SHOPINFO. The many significant correlations between cognitive attributes and module scores were not as strong as expected.

Component Structure of Cognitive Characteristics

Table 3 presents the initial principal-component solution for the cognitive characteristics and its accompanying communalities, associated eigenvalues, and percent variance accounted. Aptitude and ability measures are the prime contributors to the initial principal component. The seven components accounted for 60.1 percent of the variance of these measures.

Table 4 presents the terminal varimax solution for the cognitive attributes. Considering only those characteristics with loadings equal to or greater than .3 and discussing the measures in order of the magnitude of their weights, the derived components were interpreted as follows:

1. The first component was defined by MECHCOMP, SHOPINFO, AUTOINFO, ELECINFO, GENSCIE, WORDKNOL, SPACPERC, GENLINFO, ARTHREAS, AND VERBCOMP. The ten tests loading this component were diverse in content and probably indicative of undifferentiated general intelligence, G.

2. The tests contributing to the second component were NUMROPER, MATHKNOL, ATTNDETL, ARTHREAS, TOLRAMBQ, and GENLREAS. All of these measures seemed relevant to scholastic mathematical achievement. Consequently, this component was labeled crystallized mathematical intelligence, G_{c_m}.

3. The third component was dominated by four tests of verbal educational achievement; namely, ASSOFLUN, IDEAFLUN, VERBCOMP, and WORDKNOL. Therefore, this component was called crystallized verbal intelligence, G_{c_v}.

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[1]Because of the large number of tables in this section relative to the amount of text, the tables (and figure) are placed at the end of the section, commencing on page 9.

4. Four tests identified the fourth component: FILDINDP, INDUCTION, SPACPERC, and CATEWIDH. These primarily nonverbal reasoning tests of spatial and figural processing were thought to represent fluid intelligence, G_f.

5. The fifth component was chiefly defined by four tests of conventional educational achievement in reasoning: GENLREAS, LOGIREAS, TOLRAMBQ, and VERBCOMP. It seemed suitable to label this component, crystallized reasoning intelligence, G_{c_r}.

6. Two tests primarily loaded the sixth component: REFLIMPL and COGCOMPX. This component seemed to symbolize simplistic processing, P_s, because the first test loading this component was keyed for impulsivity and the second one was negatively weighted.

7. The seventh component was dominated by CATEWIDH, CONCSTYL, and TOLRAMBQ. Since the last two tests were negatively loaded, it appeared reasonable to call this component global processing, P_g.

Cognitive Characteristics and Module Achievement Relations

Simple and multiple correlation as well as standardized partial regression coefficients between cognitive characteristic components and module achievement scores are tabulated in Table 5. The multiple correlation coefficients indicate the relationships between all cognitive components and the achievement of each module; 10 of 11 multiple correlations were significant. For modules 1 and 4 through 9, these correlations were somewhat stable, ranging from .31 to .37. For modules 2, 10, and 11, the multiple correlations were larger, ranging from .43 to .47. Figure 1 represents these relationships indirectly by depicting the amount of variance of the achievement of each module accounted for by the cognitive components. As can be seen in Figure 1, the 10 significant multiple correlations indicated that the cognitive components explained 10 to 22 percent of the variance of module achievement.

Focusing on the individual cognitive components' contributions to the achievement of each module (presented in Table 5 and portrayed in Figure 1), a different picture appeared. The components differed in their importance regarding module achievement. None of the cognitive components manifested a stable contribution to achievement across all the modules. In fact, two of the components, P_s and P_g, only made trivial or random contributions to achievement. The G component accounted for a significant share of achievement in only three modules: 2, 10, and 11. G_{c_m} demonstrated no relationship to achievement in the first ten modules, but did contribute to module 11. The G_{c_v} component was an important influence on achievement in two modules: 2 and 5. G_f explained portions of achievement for five modules: 2, 6, 8, 9, and 10. These significant contributions were somewhat stable for just four of the five modules, ranging from .23 to .28. Lastly, the G_{c_r} component manifested significant relationships to the achievement of eight modules: 1, 2, 4, 5, 6, 7, 10, and 11. These varied from a low of .16 to a high of .31, with six being rather stable, ranging from .20 to .27. In terms of the number of significant regression coefficients, the most important components contributing to achievement through the modules were G_{c_r} and G_f respectively.

Across the modules, the number of significant components contributing to achievement ranged from one to four, with the change occurring according to no discernible pattern or obvious trend. The relative importance of the components in terms of the amount of variance accounted for, or the magnitude of the regression coefficients, varied notably throughout the modules. Various combinations of cognitive components predicted the achievement of specific modules. Different modules drew on different components to different degrees.

Classifying the subject matter of each of the 11 modules according to the task-content matrix of the instructional quality inventory (Ellis, Wulfeck, & Fredericks, 1979), revealed that the first five modules primarily required the students to remember facts, concepts, principle, and/or rules; and the last six modules, to use concepts, principles, and/or rules. The results of the multiple regression analyses suggested that, in a relative sense, G_{c_r} was more important for remembering facts, concepts, principles, and/or rules and G_f was more important for using concepts, principles, and/or rules.

To some extent, the cognitive characteristics the students possessed prior to beginning their training determined their achievement. Within limits, student proficiency throughout the modules could be predicted by using measures of these cognitive components. Changes in the proportion of variance in student performance throughout the modules accounted for by certain cognitive components represented shifts in their emphasis during the process of acquiring the course content. These shifts in predictor patterns of cognitive components appeared to be related to whether a module required the students to remember or use facts, concepts, principles, and/or rules. Different cognitive components seemed to contribute more or less to student achievement at distinct modules or stages of learning.

Table 2

Means, Standard Deviations, and Intercorrelations for the 24 Cognitive Characteristics and 11 Module Achievement Scores

Measure	Mean	SD	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5	Mod 6	Mod 7	Mod 8	Mod 9	Mod 10	Mod 11
Module 1	23.54	1.53	----										
Module 2	26.15	2.80	.41	----									
Module 3	17.46	1.50	.10	.19	----								
Module 4	9.07	.96	.29	.27	.19	----							
Module 5	27.87	2.25	.31	.37	.22	.31	----						
Module 6	19.60	2.85	.17	.29	.18	.14	.48	----					
Module 7	22.07	4.35	.10	.16	.30	.26	.19	.36	----				
Module 8	16.74	2.17	.34	.42	.25	.22	.33	.34	.24	----			
Module 9	14.87	1.96	.27	.34	.22	.27	.27	.39	.26	.50	----		
Module 10	15.08	1.61	.43	.44	.23	.25	.43	.28	.23	.47	.35	----	
Module 11	15.16	1.88	.34	.31	.22	.24	.37	.33	.33	.38	.34	.38	----
FILDINDP	5.25	3.85	.12	.25	.13	.14	.17	.25	.08	.18	.22	.21	.24
CONCSTYL	12.71	4.08	.04	.17	-.02	-.06	.07	.14	.03	.11	.22	.06	-.06
REFLIMPL	3.37	3.16	.05	-.07	.06	.00	-.15	-.10	-.07	-.10	-.13	.02	-.02
TOLRAMBQ	5.69	2.01	.00	.07	-.03	.14	.06	-.07	-.10	-.07	-.03	-.05	-.05
CATEWIDH	31.72	9.52	.17	.04	.08	.07	.11	.09	.02	.08	.05	.28	.21
COGCOMPX	72.32	17.90	-.06	-.03	-.11	-.09	-.01	.00	.06	-.05	-.11	-.10	-.15
VERBCOMP	9.06	3.21	.23	.30	.13	.11	.28	.12	.09	.18	.11	.24	.14
GENLREAS	8.27	2.87	.24	.31	.04	.21	.23	.25	.24	.18	.13	.23	.32
ASSOFLUN	11.01	4.96	.15	.27	.06	.10	.18	.10	.03	.17	.12	.15	.15
LOGIREAS	2.79	4.54	.24	.20	.08	.15	.20	.19	.30	.20	.17	.20	.34
INDUCTON	59.64	16.77	.06	.06	-.06	.05	-.00	.10	.06	.22	.10	.09	.07
IDEAFLUN	11.47	4.12	.07	.18	-.15	-.01	.14	.02	-.07	.01	.15	.04	.18
GENLINFO	58.80	6.96	.13	.26	.04	.01	.06	.04	-.02	.14	.10	.21	.11
NUMROPER	54.11	7.44	.06	.07	-.07	.02	.04	-.05	.18	.02	.08	-.01	.12
ATTNDETL	51.19	9.52	.13	-.03	.02	-.06	-.07	-.06	.05	-.09	.02	-.08	.05
WORDKNOL	59.43	6.37	.17	.19	.03	.00	.17	.07	-.09	.10	.10	.17	.13
ARTHREAS	60.33	8.47	.15	.07	-.02	.02	.08	.13	.02	.08	.06	.10	.22
SPACPERC	56.10	11.26	.06	.01	.03	.12	.02	-.04	-.01	.11	.04	.09	-.01
MATHKNOL	60.57	8.16	.23	.20	-.04	.10	.21	.20	.18	.21	.17	.16	.23
ELECINFO	60.63	6.36	.07	.25	.08	.22	.07	.15	.13	.24	.21	.23	.15
MECHCOMP	59.68	6.75	.16	.22	.00	.14	.17	.26	.13	.20	.18	.23	.20
GENLSCIE	60.40	7.68	.18	.24	.05	.15	.12	.19	.06	.18	.18	.15	.16
SHOPINFO	57.81	6.81	.08	.05	-.04	.07	.05	.07	.00	.04	-.02	.10	.13
AUTOINFO	57.52	8.13	.19	.27	.10	.13	.23	.08	.06	.16	.13	.27	.20

Notes.

1. $r(164) \geq .15$; $p < .05$.
2. Cognitive characteristics are defined on Table 1.

Table 2 (Continued)

Measure	FILDINDP	CONCSTYL	REFLIMPL	TOLRAMBQ	CATEWIDH	COGCOMPX	VERBCOMP	GENLREAS	ASSOFLUN	LOGIREAS	INDUCTON	IDEAFLUN	GENLINFO
Module 1													
Module 2													
Module 3													
Module 4													
Module 5													
Module 6													
Module 7													
Module 8													
Module 9													
Module 10													
Module 11													
FILDINDP	----												
CONCSTYL	.12	----											
REFLIMPL	11	-.15	----										
TOLRAMBQ	.07	.08	.01	----									
CATEWIDH	.13	-.05	.15	-.05	----								
COGCOMPX	.11	.00	-.21	-.06	-.19	----							
VERBCOMP	.12	.11	-.04	.12	.25	-.13	----						
GENLREAS	.20	.10	-.01	.17	.17	-.08	.35	----					
ASSOFLUN	.16	.05	-.05	.12	.13	.03	.41	.17	----				
LOGIREAS	.09	.05	-.13	.05	.17	.03	.22	.36	.10	----			
INDUCTON	.19	.11	-.16	-.06	.19	.05	.14	.15	.16	.04	----		
IDEAFLUN	.02	.02	.05	.01	.07	.01	.22	.18	.39	.05	.17	----	
GENLINFO	.05	.00	.10	.03	.09	-.13	.34	.18	.20	.18	-.03	.15	----
NUMROPER	.02	.04	-.14	-.06	.10	.03	.18	.31	.05	.11	.06	.26	.16
ATTNDETL	.02	.02	-.04	-.12	.08	.00	.00	.03	-.02	.10	.10	.08	-.04
WORDKNOL	.00	.08	.01	.03	.07	-.07	.54	.15	.30	.12	.07	.22	.43
ARTHREAS	.04	.00	-.02	.03	.07	-.11	.19	.30	.03	.25	.03	.09	.26
SPACPERC	.13	-.05	.10	.07	.06	-.11	-.01	.09	.12	-.02	.02	-.01	.13
MATHKNOL	.25	.13	-.06	.05	.12	-.02	.26	.35	.13	.23	.15	.14	.20
ELECINFO	.21	.03	-.10	.04	.10	.04	.29	.18	.15	.16	.13	.07	.37
MECHCOMP	.20	.07	.04	-.03	.12	.01	.20	.26	.14	.16	.21	.15	.37
GENLSCIE	.03	.07	-.03	.14	.10	.01	.39	.22	.21	.20	.04	.10	.35
SHOPINFO	.03	-.11	-.11	.04	.05	-.01	.24	.12	.02	.12	-.11	.07	.31
AUTOINFO	.10	.05	-.11	.03	.14	-.05	.31	.16	.03	.16	.03	.11	.35

Notes.

1. r(16[illegible]) ≥ .15; p < .05.
2. Cognitive characteristics are defined on Table 1.

Table 2 (Continued)

Measure	NUMROPER	ATTNDETL	WORDKNOL	ARTHREAS	SPACPERC	MATHKNOL	ELECINFO	MECHCOMP	GENLSCIE	SHOPINFO	AUTOINFO
Module 1											
Module 2											
Module 3											
Module 4											
Module 5											
Module 6											
Module 7											
Module 8											
Module 9											
Module 10											
Module 11											
FILDINDP											
CONCSTYL											
REFLIMPL											
TOLRAMBQ											
CATEWIDH											
COGCOMPX											
VERBCOMP											
GENLREAS											
ASSOFLUN											
LOGIREAS											
INDUCTON											
IDEAFLUN											
GENLINFO											
NUMROPER	----										
ATTNDETL	.33	----									
WORDKNOL	.21	.01	----								
ARTHREAS	.36	.10	.38	----							
SPACPERC	.07	-.03	.12	.20	----						
MATHKNOL	.41	.14	.32	.47	.10	----					
ELECINFO	.10	-.10	.42	.21	.25	.40	----				
MECHCOMP	.17	-.02	.42	.29	.34	.31	.53	----			
GENLSCIE	.13	-.09	.60	.41	.17	.43	.51	.47	----		
SHOPINFO	.11	-.06	.34	.25	.17	.15	.43	.52	.41	----	
AUTOINFO	.10	-.11	.29	.21	.14	.19	.47	.50	.34	.53	----

Notes.

1. $r(164) \geq .15$; $p < .05$.
2. Cognitive characteristics are defined on Table 1.

Table 3

Initial Principal-component Solution, Communalities (h^2), Associated Eigenvalues, and Percent Variance for the Cognitive Characteristics

Cognitive Characteristic	Initial Solution 1	2	3	4	5	6	7	h^2
FILDINDP	.24	.20	-.05	.54	.40	-.07	-.07	.56
CONCSTYL	.10	.21	.07	.3[illegible]	-.10	-.24	-.44	.46
REFLIMPL	-.10	-.15	.22	-.49	.58	.11	-.06	.66
TOLRAMBQ	.09	-.01	.41	.18	.01	-.54	.12	.51
CATEWIDH	.20	.14	.03	.02	.41	.45	.42	.60
COGCOMPX	-.07	-.02	-.17	.26	-.58	.25	.08	.51
VERBCOMP	.56	.18	.51	-.02	-.04	-.05	.10	.61
GENLREAS	.46	.42	-.01	.08	.14	-.32	.32	.63
ASSOFLUN	.32	.29	.59	.12	-.10	.24	-.03	.63
LOGIREAS	.37	.20	-.09	.12	-.03	-.20	.55	.55
INDUCTON	.20	.39	-.02	.43	.12	.45	-.13	.60
IDEAFLUN	.28	.37	.34	-.21	-.22	.33	-.00	.53
GENLINFO	.56	-.16	.21	-.24	.05	-.01	-.02	.44
NUMROPER	.39	.49	-.34	-.32	-.20	-.03	-.01	.65
ATTNDETL	.03	.45	-.36	-.25	-.09	.16	.00	.43
WORDKNOL	.70	-.04	.27	-.24	-.14	.04	-.27	.71
ARTHREAS	.69	.18	-.28	-.24	.07	-.19	-.11	.70
SPACPERC	.51	-.24	-.30	.15	.37	.05	-.16	.59
MATHKNOL	.70	.33	-.28	-.10	.04	-.18	-.16	.74
ELECINFO	.67	-.29	-.02	.23	.00	.13	-.07	.61
MECHCOMP	.73	-.25	-.16	.12	.11	.21	-.09	.70
GENSCIE	.73	-.18	.09	-.06	-.08	-.09	-.17	.62
SHOPINFO	.59	-.49	-.11	-.09	-.20	.02	.22	.69
AUTOINFO	.61	-.43	-.06	.14	-.21	.08	.27	.71
Associated Eigenvalue	5.42	2.02	1.64	1.50	1.42	1.31	1.14	
Percent Variance	22.6	8.4	6.9	6.2	5.9	5.4	4.7	

Notes.

1. Only factors with associated eigenvalues greater than or equal to 1.0 are tabulated. This minimum eigenvalue criterion ensures that only factors accounting for at least the amount of total variance of a single variable are significant.

2. Cognitive characteristics are defined in Table 1.

Table 4

Terminal Varimax Solution for the Cognitive Characteristics

Cognitive Characteristic	Terminal Solution 1	2	3	4	5	6	7
FILDINDP	.10	-.05	-.06	.68	.26	.09	-.11
CONCSTYL	-.02	.02	.09	.33	.02	-.10	-.58
REFLIMPL	-.04	-.08	.04	-.11	-.21	.73	.28
TOLRAMBQ	-.01	-.32	.13	-.08	.50	.13	-.34
CATEWIDH	.07	.03	.16	.32	.14	.14	.66
COGCOMPX	.01	.01	.02	-.04	-.13	-.70	.02
VERBCOMP	.30	-.00	.62	.03	.35	.12	-.06
GENLREAS	.11	.30	.13	.19	.68	.09	-.00
ASSOFLUN	.07	-.08	.75	.20	.09	-.03	-.02
LOGIREAS	.15	.16	.02	.04	.66	-.15	.20
INDUCTON	-.01	.14	.27	.68	-.10	-.18	.11
IDEAFLUN	.01	.24	.67	-.03	-.04	-.06	.11
GENLINFO	.52	.06	.29	-.13	.09	.24	.00
NUMROPER	.09	.77	.13	-.05	.15	-.07	-.02
ATTNDETL	-.17	.61	.01	.03	-.05	-.10	.14
WORDKNOL	.59	.20	.50	-.09	-.04	.15	-.20
ARTHREAS	.50	.59	.03	.05	.22	.20	-.13
SPACPERC	.59	.09	-.24	.37	-.02	.20	.03
MATHKNOL	.43	.63	.08	.20	.25	.11	-.20
ELECINFO	.73	-.05	.10	.23	.04	-.09	-.01
MECHCOMP	.78	.12	.05	.27	-.02	.00	.09
GENSCIE	.70	.13	.24	-.02	.09	.08	-.21
SHOPINFO	.75	-.02	-.03	-.26	.13	-.15	.15
AUTOINFO	.74	-.10	.03	-.08	.20	-.28	.16

<u>Note</u>. Cognitive characteristics are defined in Table 1.

Table 5

Simple Correlation and Standardized Partial Regression Coefficients Between Cognitive Characteristic Components and Module Achievement Scores

Component	Module Achievement Scores											
	Mod 1	Mod 2	Mod 3	Mod 4	Mod 5	Mod 6	Mod 7	Mod 8	Mod 9	Mod 10	Mod 11	v[a]
1. Undifferentiated general intelligence (G)	.13	.19*	.05	.13	.10	.16	.06	.20	.14	.23**	.17*	4.04
2. Crystallized mathematical intelligence (G_{c_m})	.15	.03	-.07	-.04	.05	.04	.14	.02	.09	-.00	.19*	11.30
3. Crystallized verbal intelligence (G_{c_v})	.12	.25**	-.04	-.01	.17*	.02	-.08	.08	.10	.10	.07	12.00
4. Fluid intelligence (G_f)	.10	.17*	.10	.14	.11	.25**	.14	.28**	.23**	.23**	.15	3.79
5. Crystallized reasoning intelligence (G_{c_r})	.20*	.24**	.11	.23**	.27**	.16*	.23**	.13	.11	.20*	.31**	3.29
6. Simplistic processing (P_s)	.09	.02	.13	.07	-.03	-.03	-.11	-.02	-.02	.11	.07	19.00
7. Global processing (P_g)	.08	-.13	.07	.03	-.04	-.03	.08	-.01	-.11	.13	.15	46.30
R	.34**	.45**	.23	.31*	.36**	.35**	.34**	.37**	.34**	.43**	47**	

Note. Since the component scores are uncorrelated in the sample, the simple correlation coefficients are also the standardized partial regression coefficients for predicting module achievement scores from the seven cognitive characteristic components.

[a]v = s/M, the coefficient of variation, where s is the standard deviation and M the mean, of the regression coefficients across all 11 modules for a specific cognitive component. This was adopted as an index of the relative stability of the regression coefficients across all modules.

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

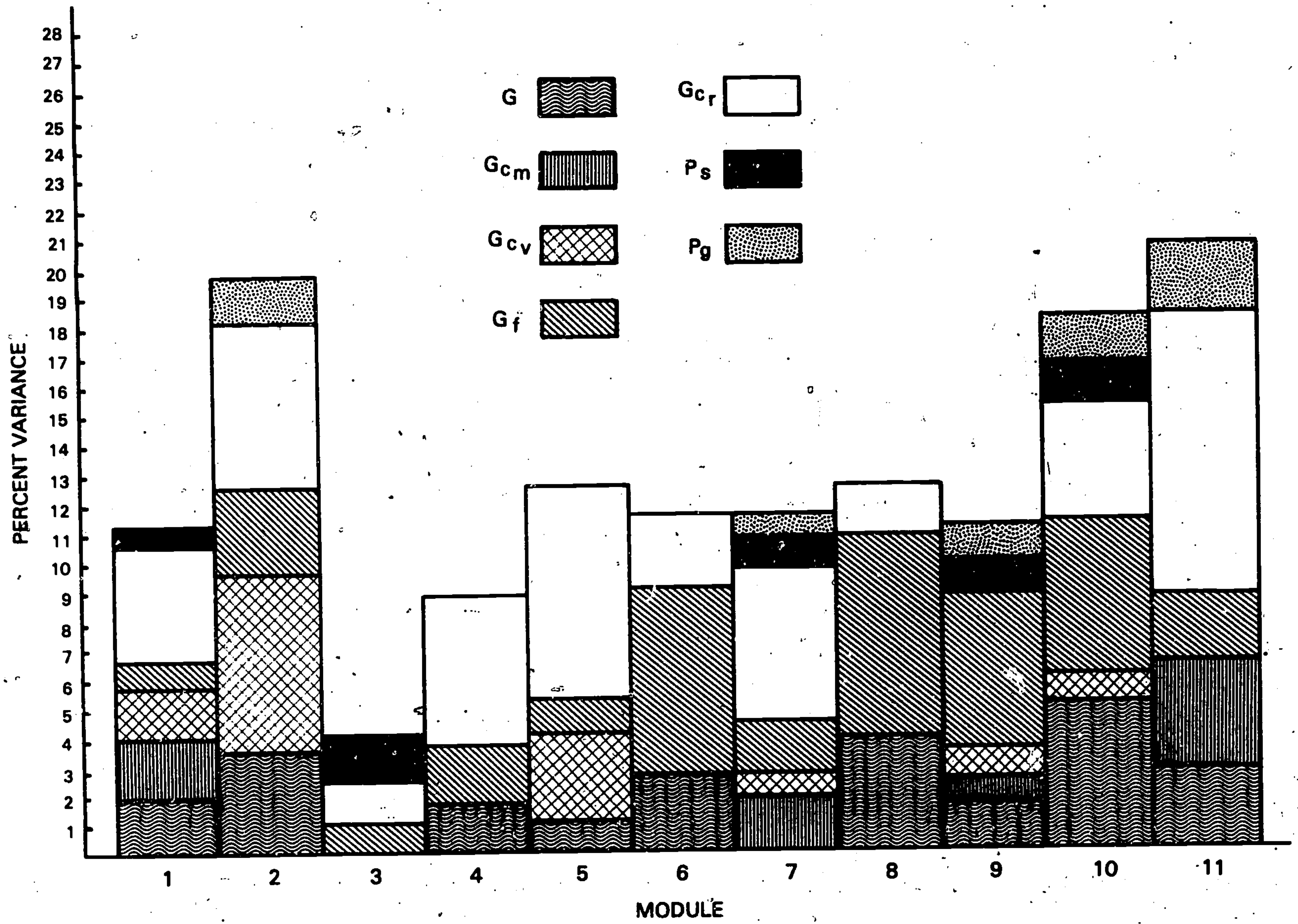

Figure 1. Amount of variance of the achievement of each module accounted for by the cognitive components.

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DISCUSSION

The results clearly indicated that considerable changes occurred in the cognitive predicators of achievement as students progressed through the sequential modules of instruction. During the acquisition of course content, the cognitive components sampled shifted noticeably in importance throughout the curriculum. This was manifested by variations in the regression coefficients of particular cognitive predictors at distinct stages of learning. Different components appeared to contribute variance at earlier and later phases of mastery. G_{c_v} seemed more important during the first half of the 11 modules; whereas G_f seemed more important during hte second half. G_{c_r}, however, appeared equally important during both phases of acquisition, since its contribution throughout most of the modules was relatively stable. These results suggest that, at early stages of acquiring complex subject matter, the C_{c_v} component played somewhat of a major role. As learning continued through the modules, this cognitive component became less important as a determiner of individual differences in mastery. At the same time, G_f increased in importance as learning continued until it was one of two components that entered to a significant extent and number at the latter stages of mastery. As the students progressed through the entire curriculum, the contribution G_c made to their acquisition of the course content nevertheless remained somewhat stable. It was implied that, after progressing through hierarchical modules, individual differences in learning depend more on certain cognitive components and less on others than they did when beginning to acquire the course contents. Earlier in learning, the use of specific components is minimal but prerequisite for later acquisition. Yet, other cognitive components may remain rather unchanging during the mastery of the complete curriculum.

With respect to conducting ATI research, changes in the component predictor pattern over the course of learning underscored the necessity of ascertaining what aptitudes are contributing to acquisition at distinct stages. It was highly likely that the cognitive processing involved in the initial phases of learning differed from the processing at terminal phases of acquisition. This suggested the requirement for protocol analyses of the cognitive processing involved in early, intermediary, and later phases of learning. It seemed possible that particular aptitudes contributing to learning at distinct stages reflect the presence of prerequisite cognitive competencies, schemata, knowledge, and learning sets required to acquire the subject matter at particular phases of mastery.

The instability of the relationships of some cognitive components across distinct stages of learning suggested the importance of concentrating on the process of change from ignorance to competence. Glaser (1976) has aptly explained the transformation from novice to expert during the course of mastering complex subject matter or intricate skill as follows:

> (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)

Burns (1980) mentioned that alterations in aptitude demands through learning may form the basis of the transition from novice to expert performance. In attempting to account for the nature of such shifts, he hypothesized that instructional treatments are composed of two distinct origins of aptitude requirements: those related to the method of instruction and those related to the content of instruction. Each of these sources demands a specific type of aptitude. It was postulated that the method of instruction primarily requires the G_c aptitude; and the content, the G_f aptitude.

According to Snow (1980), G_c, Cattell's (1971) crystallized ability, represents a general dimension of measures that are good predicators of conventional educational achievement or scholastic ability (e.g., verbal, quantitative, vocabulary, reading comprehension, information, mathematical, and prior scholastic achievement). G_f, Cattell's (1971) fluid ability represents another general dimension of measures and probably represents the assembly and control processes necessary to structure adaptive strategies for solving novel and immediate problems (e.g., abstract, spatial, figural, and nonverbal reasoning tests).

In attempting to answer why G_c measures are often better predictors of learning outcome than are G_f measures, Snow (1980) speculated:

> One reason may be that 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 furture learning. Because these are products of past education, and because education is in large part accumulative, transfer relations between past and future learning are 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, whereas G_f may represent new assemblies of performance processes needed in more extreme adaptations to novel situations. The distinction, then, is between long-term assembly for transfer to familiar new situations versus short-term assembly for transfer to unfamiliar new situations. (p. 37)

This distinction between G_c and G_f led Burns to theorize that, since G_c confers pervasive learning skills--not specific knowledge--then G_c itself transcends the particular content of instruction. To the extent that this type of instruction had been experienced by students previously, G_c would inculcate a general learning set to process and interpret this kind of instruction. Consequently, Burns posited that G_c could manifest a nearly stable relationship over the course of learning if there were no pronounced changes in the method of instruction. This could not be so with G_f. But it was possible, speculated Burns, that the content of the instruction periodically and differentially requires the processing reflected by G_f. Because the content of instruction usually changes during a course, it was reasonable to speculate that the G_f learning relationships demonstrate instability as students progressed through a particular curriculum from novices to experts. Burns hypothesized that, for these reasons, G_c typically manifests more consistent ATI results than specialized aptitudes like G_f (Cronbach & Snow, 1977).

In this study, both G_f and G_{c_r} demonstrated somewhat stable relationships to achievement. However, G_f was rather stable only for the second half of instruction; and G_{c_r}, primarily for approximately the first two-thirds of instruction. The content of the first five modules principally required students to <u>remember</u> facts, concepts, principles, and/or rules; and the last six modules, to <u>use</u> concepts, principles, and/or rules. These results seem to imply that the content of instruction and the <u>task demanded of the students</u> as they progress through the course determine the nature of the relationship of G_f to achievement. The content of instruction changed from one module to the next throughout the entire course. Nevertheless, G_f exhibited a fairly stable relationship to mastery for the second part of the curriculum. The changing course content had no apparent impact upon the stability of G_f. The type of processing task required of the students seemed to be more important though regarding G_f. If the cognitive task demands remained more or less constant, G_f's relationship to achievement would remain more or less stable. Possibly, to perform a particular processing task, students would have to resort to the prerequisite cognitive competencies, schemata, structures, knowledge and representational systems that are assessed by specific aptitudes. If the task demands do not change, then the aptitude requirements do not change. Conversely, if the task requirements are altered, then the aptitude demands are altered. This interpretation regarding G_f differs from Burns' speculations.

Insofar as G_c is concerned, the data obtained in this study seem to suggest that G_{c_r} is independent of course content, while dependent upon task demands and the method of instruction. G_{c_r} exhibited a fairly stable relationship to achievement throughout the earlier part of the curriculum, which involved primarily remembering facts, concepts, principles, and/or rules. The method of instruction remained the same while the contents of each module varied through the entire curriculum. During the final phase of instruction, when the students were using concepts, principles, and/or rules, the relationship of G_{c_r} to learning became unstable. With the method of instruction and task demands constant, while the content changed during the initial two-thirds of the course, the relationship of G_{c_r} to achievement was somewhat stable. In the final third of the curriculum, the method of instruction was still constant while the content and task requirements changed. The introduction of change in task demands was associated with the unstable relationship of G_{c_r} to learning. This implied to some extent that the association of G_{c_r} to achievement was contingent upon task requirements and the method of instruction while being unsubordinated to course contents. This speculation differed from Burns' suppositions.

The CMI system used to implement mastery learning of the BE/E curriculum probably can be considered a "new" learning situation in Snow's (1980) scheme of things:

> What constitutes a "new" learning situation is not really clear. But one can predict that as an instructional situation involves combinations of new technology (e.g., computerized instruction, or television), new symbol systems (e.g., computer graphics or artistic expressions), new content (e.g., topological mathematics or astrophysics), and/or new contexts (e.g., independent learning, col-laborative teamwork in simulation games), G_f should become more important and G_c less important. (p. 59)

CMI can be viewed as a relatively new technology. The comprehension of many circuit schematics and the solution of numerous algebraic equations can be thought of as new symbol systems. The perception of several relationships among voltage, resistance, and current, as well as the reduction of complicated circuits to simpler ones, can represent new content. Lastly, self-study and self-pacing together with mastery learning can be regarded as new contexts. According to Snow, the relationship of G_c to achievement should be stronger in ordinary educational environments. This has been established in much of the ATI research (Cronbach & Snow, 1977).

If the typical instructional treatment is altered as in computer-managed mastery learning, then the strength of the association of G_c to learning is lessened and an ATI will likely appear. Consequently, students who lack well-developed, conventional, academic aptitudes will benefit from the unorthodox, educational treatment, while those who possess these skills may not be able to apply them. Computer-managed mastery learning is individualized instruction based on carefully defined objectives, hierarchical in its content, modular in its presentation and assessment, with diagnostic achievement tests and immediate feedback on student progress; it structures, segments, and directs learning for lower-aptitude students--doing for them what they cannot do well for themselves. Snow maintained that this unconventional instructional treatment is probably dysfunctional for more apt students--those who can organize and control their own learning because of the nature of the cognitive processing required and acquired previously by conventional, educational experiences. Therefore, G_c aptitude is probably of no particular advantage in novel instructional situations like computer-managed mastery learning. Within this context, Snow expected that G_f would be associated with achievement in innovative instructional situations--different from those the students experienced in the past. In these novel educational environments, G_c will likely be irrelevant; and G_f, relevant. The data obtained herein, however, demonstrated that not only is G_f pertinent to learning in new instructional situations but so is G_c (i.e., its components). This suggested that some unconventional educational settings are not necessarily dysfunctional for abler students. In these situations, they can just as easily exercise and capitalize upon those skills developed and applicable in more traditional instructional situations.

CONCLUSIONS AND RECOMMENDATIONS

It was highly likely that the cognitive processing involved in the initial phases of learning differed from the processing at terminal phases of acquisition. This suggested the requirement for protocol analyses of the cognitive processing involved in early, intermediary, and later phases of learning. It must be determined whether particular aptitudes that contribute to learning at distinct stages reflect the presence of prerequisite cognitive competencies, schemata, knowledge, and learning sets required to acquire the subject matter at particular phases of mastery. The instability of the relationships of some cognitive components across distinct stages of learning suggested the importance of concentrating on the process of change from ignorance to competence.

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