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ABSTRACT

Two courses on logic gates were administered to 1,191 male and female recruits in Basic Military Training in 3 studies (448, 431, and 312 subjects, respectively) to evaluate the relative validities of the Armed Services Vocational Aptitude Battery (ASVAB) and the Learning Abilities Measurement Program (LAMP) tests in predicting individual differences in the acquisition of declarative knowledge (measured by the accuracy in solving problems) and the development of procedural skill (measured by the time required to solve problems). In general, the LAMP tests added about 20 percent unique valid variance to the ASVAB tests in predicting these criteria. Furthermore, for both criteria, the LAMP test alone accounted for more variance than did the ASVAB tests alone. Analyses indicate that the advantage of the LAMP tests was neither due to concurrency effects, nor obtained at the expense of excessive testing time. Although LAMP tests and the criterion tests used common methods, arguments are presented contending that most of the covariance associated with common methods was meaningful to the task being learned and performed. Thirty tables in the text and six more in two appendixes present study findings. (Contains 22 references.) (Author/SLD)

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ARMSTRONG LABORATORY

COMPARATIVE VALIDITIES OF ASVAB AND LAMP TESTS FOR LOGIC GATES LEARNING

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13. ABSTRACT (Maximum 200 words)

Two courses on logic gates were administered to samples of airmen in Basic Military Training to evaluate the relative validities of ASVAB and LAMP tests in predicting individual differences in the acquisition of declarative knowledge (measured by the accuracy in solving problems) and the development of procedural skill (measured by the time required to solve problems). In general, the LAMP tests added about 20% unique valid variance to the ASVAB tests in predicting these criteria. Furthermore, for both criteria, the LAMP tests alone accounted for more variance than did the ASVAB tests alone. Analyses indicated that the advantage of the LAMP tests was not due to concurrency effects, nor was it obtained at the expense of excessive testing time. Although LAMP tests and the criterion tests used common methods, arguments are presented contending that most of the covariance associated with common methods was meaningful to the task being learned and performed.

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PREFACE

The conduct of this research and the preparation of this report was supported under a contract designed to service the Air Force Learning Abilities Measurement Program (LAMP), a multi-year program of basic research conducted at the U.S. Air Force Human Resources Laboratory (AFHRL)*, and sponsored by the Air Force Office of Scientific Research (AFOSR). The goals of this program are to specify the basic parameters of learning ability, to develop techniques for the assessment of individuals' knowledge and skill levels, and to explore the feasibility of a model-based system of psychological assessment. The present study reports on applied, rather than basic research, and was conducted to help determine whether the new types of computer measures coming out of LAMP research show promise for ultimately improving the Air Force personnel selection and classification system. The author wishes to thank Scott Chaiken, Patrick Kyllonen, Dan Woltz, Bill Alley, Valerie Shute, and Bob Young for their review of the draft manuscript and their helpful comments. Thanks are also given to Bill Tirre and Malcolm Ree for their assistance in obtaining data and information used in correcting validities and intercorrelations for restrictions in range due to selection. Finally, special appreciation is expressed to Terri Purdue who both programmed the logic gates courses and prepared all data for the statistical analyses, and to Janice Hereford, who programmed data for the restriction of range corrections.

* AFHRL has been redesignated Human Resources Directorate, Armstrong Laboratory.

COMPARATIVE VALIDITIES OF ASVAB AND LAMP TESTS FOR LOGIC GATES LEARNING

SUMMARY

Two short computer courses were designed to teach basic airmen how to identify various types of logic gates and to determine their output signals as a function of their input signals. In Study 1, 448 subjects received training on simple gates with and without negations. After training, they were required to solve six 36-item blocks of gate problems without negations, and four 36-item blocks of gate problems with negations. Instructive feedback was provided after each incorrect response. In Study 2, 431 subjects were trained on simple gates and required to solve eight 36-item blocks of simple gate problems without negations, and one 30-item block of simple gate problems with negations. Instructive feedback was given after each incorrect response. These blocks were followed by two 60-item blocks of mixed simple gates (with and without negations), training on complex gate circuits, and, finally, four 54-item blocks of mixed simple gates and complex gate circuits.

Subject responses were scored both for accuracy and for latency. Accuracy scores were used as criteria indicating the acquisition of declarative knowledge concerning the rules for solving logic gate problems. Latency scores at each stage were used as criteria indicating the level of procedural skill acquired up to that stage. In each study, the subjects were administered LAMP tests designed to measure working memory capacity and information processing speed. ASVAB test scores were obtained for subjects from operational files.

One of the primary purposes of the study was to determine the relative power of the the ASVAB tests and of the LAMP tests in predicting the learning criteria from the logic gate courses. It was also considered important to determine how much unique valid variance the LAMP tests could contribute to the ASVAB tests in predicting these criteria. In general, the LAMP tests were found to add about 20% unique valid variance to the ASVAB in predicting both accuracy and latency block averages in the two courses. When the intercorrelations and validities were corrected for restrictions of range due to selection, the estimated contributions of LAMP tests to ASVAB tests in accounting for criterion variance ranged from 17% - 21% in the U.S.Air Force (USAF) applicant sample, and from 13% - 20% in the 1980 youth sample. Furthermore, against all criteria, LAMP tests alone accounted for more variance than did ASVAB alone. Analyses were conducted in a third study which indicated that the advantage of the LAMP tests over the ASVAB tests was not the result of a concurrency effect, nor was it obtained at the expense of excessive testing time. The results are viewed as encouraging with respect to the power of LAMP tests to predict meaningful learning criteria.

INTRODUCTION

The Learning Abilities Measurement Program (LAMP) is a basic research program jointly sponsored by the Air Force Office of Scientific Research (AFOSR) and the Air Force Human Resources Laboratory (AFHRL). It supports studies on the identification and measurement of abilities which can account for individual differences in the acquisition of knowledge and skills. The present framework for the LAMP program is loosely modeled after Anderson's (1983) ACT* theory, and hypothesizes that individual differences in learning efficiency arise from four primary sources: a) the breadth and depth of declarative knowledge brought to the learning situation; b) the breadth and depth of procedural skills brought to the learning situation; c) information processing speed capabilities; and d) working memory capacity (Kyllonen, 1985b). Research during the past several years has been focused on defining, measuring and validating abilities relating to processing speed and working memory capacity (Kyllonen,1985a; Kyllonen & Christal, 1989; Kyllonen & Christal, 1990; Kyllonen, Tirre, & Christal, 1988; Woltz, 1988).

Although LAMP is a basic research program, it is nevertheless goal oriented. The ultimate goal is to improve the U.S. Air Force (USAF) personnel selection and classification system. In order to gauge whether progress is being made toward this goal, it is desirable to periodically validate new tests against meaningful learning criteria. Ultimately, there will be a large-scale validation against school and job performance criteria. However, it may be some time before the results of basic research will warrant this type of costly validation effort. In the meantime, in order to generate meaningful learning criteria for test validation, the approach has been to train individuals to proficiency on operational tasks which are brought into the laboratory. A new experimental training facility, the Complex Learning Assessment (CLASS) laboratory, has been established for this purpose. Individuals participating in CLASS experiments spend approximately 1 to 1 1/2 days taking experimental LAMP tests, and then up to 30 hours taking a training course by means of intelligent tutors administered by microcomputers.[1] Rich information concerning skill and knowledge acquisition is recorded during course administration, which, in turn, is used to investigate learning behaviors and to validate scores from the concurrently administered experimental LAMP tests. So far, data have been collected from two such courses, one in computer programming and one in electrical circuits. A third course, dealing with flight-engineering tasks, is being constructed (Shute, in press-a; Shute, in press-b; Shute & Glaser, 1990, Shute & Pena , 1990).

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[1]There are wide individual differences in both the time required to take the experimental tests and to complete the training courses.

Although data from CLASS experiments are extremely useful, developing and administering intelligent tutors is a somewhat slow and expensive process. It requires more than a year to develop and administer a course. To supplement this effort, attempts have been made recently to develop short (1- to 2-hour) courses, on narrow subjects, which can be administered to samples of airmen in Basic Military Training. The LAMP project has access to samples of basic airmen for approximately 3 hours of experimental testing during their 11th training day. This paper describes the development of courses on electronic logic gates, which were used in three studies to validate LAMP tests and tests from the Armed Services Vocational Aptitude Battery (ASVAB).

Logic gates were chosen for the course subject-matter for several reasons. First, they have been used by other investigators to study skill acquisition (Carlson, Khoo, Yaure & Schneider, 1990). Second, they lend themselves to the development of test items at various difficulty levels.[2] Third, gate problems were predicted to be well suited for studies on procedural skill development. Finally, and this is the most important reason, previous research has demonstrated that knowledge of logic gates is a distinguishing factor between "skilled and less-skilled" 1st-term airmen working in avionics (Gitomer,1984). In light of these observations, it was judged that a short course on logic gates would fill the requirement for a meaningful learning task which could be administered under laboratory conditions in less than 2 hours.

GENERAL APPROACH

The present paper reports the results of three studies. The first half of Study 1 involved training on AND, OR, and XOR gates, followed by six blocks of test questions on simple gates without negations. In the second half of Study 1 course instructions were provided on the effects of negations, and included four blocks of questions on simple gates with negations. In both sections, instructive feedback was provided after each incorrect response.[3]

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[2]Simple AND or OR gates without negations are easy. XOR gates are somewhat more difficult. Gates with negations are considerably more difficult to learn than are gates without negations. Complex circuits involving several gates can be very difficult to solve.

[3]A distinction is made between testing blocks and analysis blocks. Study 1 included three 72-item testing blocks of simple gates without negations and two 72-item testing blocks of simple gates with negations. For analysis purposes, these testing blocks were split into six and four 36-item blocks, respectively. Study 2 included four 72-item blocks of simple gates without negations, which were split into eight 36-item blocks for the analysis. In all other instances, testing blocks were identical to analysis blocks. Summary feedback was provided to subjects after each testing block.

In Study 2, subjects were given a pre-test to determine their level of "going-in" knowledge. This was followed by: (a) instructions on simple AND, OR, and XOR gates; (b) eight blocks of test questions on simple gates without negations, with instructive feedback after incorrect responses; (c) instructions on negations; (d) one block of simple gates with negations, with instructive feedback after incorrect responses; (e) two blocks of mixed simple gates, with and without negations; (f) instructions on complex gate circuits; and (g) three blocks of test questions on mixed simple and complex gates, some with and some without negations.

In both Study 1 and Study 2, subjects were administered experimental tests developed in the LAMP program. Scores from the ASVAB were obtained for each subject from operational files. A series of analyses was conducted to determined how well individual differences in the acquisition of declarative knowledge (reflected in accuracy scores) could be predicted by LAMP tests alone and by ASVAB tests alone. Analyses were also conducted to see how much predictive validity the LAMP tests added to ASVAB tests in the prediction of gates course criteria. Similar analyses were conducted to determine the power of the LAMP and ASVAB tests to predict the development of procedural skill, which was reflected in the time required to solve gate problems.

One of the concerns in Studies 1 and 2 was that the LAMP tests were administered concurrently (in the same test session) with the gates course, while the ASVAB tests had been administered several months earlier in operational testing stations. Previous research has suggested that concurrent administration of predictor and criterion measures may lead to a minor inflation in estimated validity coefficients (Christal, 1989; Divgi, 1990). Study 3 was conducted to evaluate the magnitude of this concurrency effect. It involved the re-administration of several ASVAB tests with the Study 2 gates course. This made possible a comparison of predictive (non-concurrent) and concurrent validity coefficients for the same criteria.

More detailed descriptions of the gates courses are given in the sections which follow, and abbreviated descriptions of the LAMP and ASVAB tests are provided in Appendix A.

METHOD

Subjects

For Study 1, the subjects were 448 military recruits who were tested on the 6th day of their basic military training at Lackland Air Force Base, Texas. Of these, 94% were males and 6% females.

Studies 2 and 3, included 431 and 312 subjects, respectively, who were tested on the 11th day of their basic military training. In Study 2, 7.6% of the subjects were females, while in Study 3, 28.2% were females. The larger proportion of females in Study 3 was fortuitous. Testing samples were drawn from training flights as they arrived, and such flights were either all-male or all-female. Not included in the above samples were subjects for whom ASVAB scores could not be obtained, those who did not complete the course and experimental tests in the available testing time, and up to 1% who were eliminated because they were extreme outliers on the course on one or more of the tests.

Testing Facility

The testing facility consisted of partitioned testing stations in a large air-conditioned room. Each station was equipped with a Zenith Z-248 microcomputer with a 20 Mb hard disk for storing course materials, test items, and subject responses. A standard keyboard was used for response entry, and an enhanced graphics adaptor (EGA) and display monitor (640 x 350 color resolution) was used for stimulus presentation.

Procedure

For each testing session, a proctor briefed subjects on the purposes of the testing, and then assigned them to testing stations. A computer program provided subjects with general information about the LAMP program; described use of the keyboard; told how to ask questions of the proctor; provided information about breaks; warned against talking with others about the test during breaks; and indicated what to do when the course and all tests were completed.

The subjects read and responded to information in accordance with the Privacy Act. They entered their Social Security Number, which was required for use in acquiring their ASVAB scores, and answered questions concerning their gender, education, and race. Then they responded to a short questionnaire concerning the use of English as a first language at home and in school.

In each of the three studies, the subjects were given a general description of logic gates, and answered 12 questions concerning whether they had studied logic gates in school, had read about them in books, magazines, or newspapers, knew how they operate, or had used them in building electronic projects. They also answered questions concerning prior experience with microcomputers, interest in electronics and science, and whether they had sought an assignment in a USAF electronics career ladder.

In Studies 2 and 3, the above questionnaire was administered immediately before or immediately after a pre-test designed to measure subjects' levels of incoming knowledge specifically relating to logic gates. These gate problems were taken directly from the course which was to follow, except that additional foils (distractors) were generated to attract individuals who had little or no knowledge concerning logic gates.

In all three studies, the subjects were provided with a short training course on the shapes of AND, OR, and XOR gates, and were asked to associate the names with their respective shapes. This gate familiarization was followed with a 30-item test in which gates were presented on the screen and the subjects were asked to indicate the associated name by pressing an appropriate key. After each incorrect response, the subjects were informed of their incorrect response and were presented, for 10 seconds, with a screen which displayed all three gates and their associated names. In all three studies, the first two sections of the course were identical, except for the number of test problems and the method used for timing instruction frames. Each successive screen was displayed for a specific period, and then the next screen automatically appeared. The keyboard was 'locked-out', except during the times the subject was required to enter responses to problems. In Study 1, the direction screens contained statements concerning time allowances (e.g. "You will have 45 seconds to study information on this screen."). In Studies 2 and 3, these time allowance statements were replaced by timing bars at the top of the screen, which became shorter with the passing of each second. Otherwise, the directions for the first two sections were identical in all three studies, and can be summarized as follows:

(1) A 45-second screen describing logic gates and displaying a gate drawing with labeled input leads, gate body and output lead.

(2) A 45-second screen describing the input-output rules for the AND gate, with two examples provided.

(3) A screen providing six labeled examples of AND gates, some with two and some with three input leads. In Study 1, these examples were presented all at once on a 45-second screen. In Studies 2 and 3, these examples were added to a screen one-at-a-time, after specified periods of time. In all studies, the correct output signals (problem answers) were provided.

(4) The subjects were given a test containing eight AND gates, in which they indicated whether the output signal was HI or LO by pressing the 'H' or 'L' key. After each incorrect response, the subject was shown a screen for ten seconds which presented rules for the particular gate-type in question.

(5) The subjects were shown a series of instruction screens for OR gates. This was followed by an 8-problem test on OR gates, with a 10-second rule-feedback for each item missed.

(6) The subjects were shown a series of instruction screens for XOR gates. This was followed by an 8-problem test on XOR gates, with a 10-second rule-feedback for each item missed.

(7) The rules for AND, OR, and XOR gates were repeated.

(8) In Study 1, the subjects solved six 36-item blocks of mixed AND, OR, and XOR gates, without negations. After each incorrect response, the subject was provided with a 10-second instructive feedback frame which displayed the pictures and rules for all three gate-types, with the missed gate-type highlighted. Studies 2 and 3 differed only in the fact that they included eight blocks (as opposed to six in Study 1), and the feedback screens contained timing bars. In all studies, summary information concerning percent correct and median response latency was given at the end of each testing block.

(9) Instead of complicating the study with definitions of NAND, NOR gates and INVERTERs, the present studies made use of negation symbols on input and output leads. The subjects were first taught the impact of a negation on the output signals of AND, OR, and XOR gates, with six examples provided. Then the impact of negations on input leads was explained, again with six examples given. Finally, an example was given with negations on both input and output leads. As in the case of simple gates without negations, the study frames were presented for specific time periods, with timing bars used in Studies 2 and 3. In Study 1, the subjects were administered four problem blocks, in which all items contained negations on the input leads, output leads, or both input and output leads. Latency feedback was given for correct responses, and instructive feedback was given for incorrect responses. Summary feedback on percent correct and median latency was provided after each testing block. In Studies 2 and 3, only one 30-item test block of gates with negations was given.

In Studies 2 and 3, the one block of simple gates with negations was followed by two 60-item blocks containing a mixture of simple gates with and without negations. Then the subjects were given instructions on how to determine the final output signal of complex circuits involving two input gates, with or without negations, and one output lead with or without negations. Finally three 54-problem blocks of were presented, each of which contained a mixture of simple gates (with and without negations), and complex gates (with and without negations). Feedback in the form of CORRECT/WRONG and response latency was provided for each of the items in the mixed simple gates and the mixed simple/complex gates blocks, along with summary data at the end of each testing block. Although details will not be provided, the blocks within sections were balanced in terms of item types.

Figure 1 presents the abbreviations for the predictor tests, and Figure 2 presents abbreviations for the course criteria. Both sets of abbreviations are used in tables throughout the remaining part of this paper.

Figure 1. Test Abbreviations, Titles and Study Usage

Abbreviation	Title	Study1	Study2	Study3
ASVAB				
GS	General Science	X	X	
AR	Arithmetic Reasoning	X	X	X
ARR	Arithmetic Reasoning, Retest			X
WK	Word Knowledge	X	X	
PC	Paragraph Comprehension	X	X	
NO	Numerical Operations	X	X	
CS	Coding Speed	X	X	
AS	Auto and Shop Information	X	X	
MK	Mathematics Knowledge	X	X	X
MKR	Mathematics Knowledge, Retest			X
MC	Mechanical Comprehension	X	X	X
MCR	Mechanical Comprehension, Retest			X
EI	Electrical Information	X	X	
LAMP				
CRA	Choice Reaction, Accuracy	X	X	
CRL	Choice Reaction, Latency	X	X	
PIA	Physical Identity, Accuracy	X	X	
PIL	Physical Identity, Latency	X	X	
NIA	Name Identity, Accuracy	X	X	
NIL	Name Identity, Latency	X	X	
MIA	Meaning Identity, Accuracy	X		
MIL	Meaning Identity, Latency	X		
NFA	Number Fact Retrieval, Accuracy	X		
NFL	Number Fact Retrieval, Latency	X		
ABA	Grammatical Reasoning, Accuracy	X	X	
ABL	Grammatical Reasoning, Latency	X	X	
NRA	Number Reduction, Accuracy	X		
DSA	Digit Span, Accuracy	X		
NAA	ABC Numerical Assignment, Accuracy	X	X	
GKA	General Knowledge, Accuracy		X	
GKL	General Knowledge, Latency		X	
WAA	Word Association, Accuracy		X	
FRA	Figure Recognition, Accuracy		X	
MCA	Mental Character Generation, Accuracy		X	

Notes: See Appendix A for test descriptions.

Figure 2. Codes, Definitions, and Study Usage for Logic Gates Course Blocks

Code	Description	Study1	Study2	Study3
1-1	Simple Gates, No Negations, Block 1	36	36	36
1-2	Simple Gates, No Negations, Block 2	36	36	36
1-3	Simple Gates, No Negations, Block 3	36	36	36
1-4	Simple Gates, No Negations, Block 4	36	36	36
1-5	Simple Gates, No Negations, Block 5	36	36	36
1-6	Simple Gates, No Negations, Block 6	36	36	36
Av1	Simple Gates, No Negations, Average, Blks 1-6	216		
1-7	Simple Gates, No Negations, Block 7		36	36
1-8	Simple Gates, No Negations, Block 8		36	36
Av1	Simple Gates, No Negations, Average, Blks 1-8		288	288
2-1	Simple Gates, With Negations, Block 1	36	30	30
2-2	Simple Gates, With Negations, Block 2	36		
2-3	Simple Gates, With Negations, Block 3	36		
2-4	Simple Gates, With Negations, Block 4	36		
Av2	Simple Gates, With Negations, Blks 1-4	144		
3-1	Mixed Simple Gates, With & Without Negations, Block 1		60	60
3-2	Mixed Simple Gates, With & Without Negations, Block 2		60	60
Av3	Mixed Simple Gates, With & Without Negations, Blks 1-2		120	120
4-1	Mixed Simple & Complex Gates, With & Without Neg. Blk 1		54	54
4-2	Mixed Simple & Complex Gates, With & Without Neg. Blk 2		54	54
4-3	Mixed Simple & Complex Gates, With & Without Neg. Blk 3		54	54
Av4	Mixed Simple & Complex Gates, With & Without Neg. Avg. 1-3		162	162
AVG	Average Across All Course Blocks	360	600	600

Notes: Codes are used in tables throughout the paper to identify blocks of accuracy and latency scores. The Av1 values are averages across six blocks in Study 1, and across eight blocks in Study 2. Table values indicate the number of items in the various blocks and block averages.

STUDY 1

Learning Performance

Study 1 involved administration of six 36-problem blocks of simple gates without negations and four 36-item blocks of simple gates with negations. Table 1 presents the means and standard deviations for the accuracy scores and for the median latency scores for these various blocks.

Table 1. Means and Standard Deviations for Study 1 Course Blocks and Averages

BLK CODE	1-1	1-2	1-3	1-4	1-5	1-6	Av1	2-1	2-2	2-3	2-4	Av2	AVG
ACCURACY													
Mean	79.2	87.8	91.7	93.2	94.8	95.2	90.3	83.8	87.0	89.2	89.6	87.4	87.9
S.D.	11.8	10.2	8.1	7.4	6.9	6.4	6.9	15.4	13.8	12.8	12.6	12.6	7.9
LATENCY													
Mean	1.87	1.58	1.43	1.27	1.21	1.17	1.37	3.39	2.98	2.74	2.74	2.95	1.80
S.D.	.53	.43	.39	.29	.29	.27	.30	.87	.76	.71	.73	.70	.40

Notes: Block codes are defined in Figure 2.

It is clear from data in Table 1 that both declarative and procedural learning took place across the entire course. In the case of simple gates without negations, the mean accuracy rose from 79.2% in Block 1 to 95.2% in block 6, while the standard deviations dropped from 11.8% to 6.4% across these same blocks. Since the "going-in" knowledge about logic gates for the basic airmen is near zero (see Study 2), the mean accuracy level of 79.2% for problems in Block 1 must be attributed to learning which took place in the course prior to Block 1, and to the instructional feedback given for problems missed within Block 1. The remaining learning (reflected in the increase in means from 79.2% to 95.2%) can be attributed to learning from the instructive feedback given for problems missed after Block 1.

The group data also reveal a systematic increase in the development of procedural skill. The mean of the median response latencies dropped from 1.87 seconds in Block 1 to 1.17 seconds in Block 6, and the standard deviations for latencies dropped from .53 to .27 seconds across these same Blocks.

In the case of gates with negations, the learning rates were considerably lower, rising from 83.8% accuracy in Block 1 to 89.6% accuracy in Block 4, with the associated standard deviations dropping from 15.4% to 12.6%. There was some indication of the development of procedural skill during the first three blocks, but reductions in latencies leveled off after Block 3.

Table 2 reports the intercorrelatons of accuracy scores for all problem blocks. The intercorrelation matrix for the six blocks of gates without negations (labeled 1-1 to 1-6) was in the form of a pseudo simplex, the highest values being between adjacent blocks and the lowest values being between the blocks furthermost removed from each other. The same is true for the four blocks of gate problems with negations. The magnitudes of the correlations between adjacent blocks provide a rough indication of the stability of individual differences in performance across those blocks. The lower intercorrelations between the blocks of gates without negations can be partly attributed to a restriction in range due to a ceiling effect. In Blocks 1-6, 31.7% of the subjects made perfect scores, while another 29.9 % missed only one item.

Table 2. Intercorrelations of Accuracy Scores from Study 1 Course Blocks

VAR	1-1	1-2	1-3	1-4	1-5	1-6	2-1	2-2	2-3	2-4
1-1	1.00									
1-2	.68	1.00								
1-3	.59	.72	1.00							
1-4	.48	.61	.69	1.00						
1-5	.43	.56	.60	.73	1.00					
1-6	.39	.49	.56	.68	.76	1.00				
2-1	.39	.42	.42	.44	.50	.49	1.00			
2-2	.42	.45	.50	.54	.61	.58	.83	1.00		
2-3	.42	.48	.49	.59	.63	.59	.76	.85	1.00	
2-4	.44	.53	.48	.58	.64	.60	.74	.81	.86	1.00

Notes. Block variable codes are defined in Figure 2.

Table 3 presents the intercorrelations among the latency scores for the various learning blocks. Again, the values in this matrix are in the form a pseudo simplex, with the latter adjacent blocks of gates without negations correlating in the upper .80s.

Table 3. Intercorrelations of Latency Scores from Study 1 Course Blocks

VAR	1-1	1-2	1-3	1-4	1-5	1-6	2-1	2-2	2-3	2-4
1-1	1.00									
1-2	.74	1.00								
1-3	.56	.75	1.00							
1-4	.54	.73	.88	1.00						
1-5	.48	.67	.81	.85	1.00					
1-6	.47	.62	.77	.82	.88	1.00				
2-1	.55	.56	.51	.50	.48	.49	1.00			
2-2	.51	.54	.50	.52	.48	.51	.86	1.00		
2-3	.43	.46	.46	.48	.44	.46	.73	.80	1.00	
2-4	.40	.42	.36	.38	.36	.41	.72	.75	.80	1.00

Notes. Block variable codes are defined in Figure 2.

Factor Analysis

The names and descriptions of the ability tests administered to subjects in Study 1 are presented in Appendix A. In the case of ASVAB tests, all scores were measures of accuracy, although the Numerical Operations and Coding Speed tests were administered under speeded conditions, and the resulting scores were based on the number of correct answers recorded during the allotted time. Nine tests were selected from the LAMP program for inclusion in Study 1, all of which were designed to be measures of information processing speed or working memory capacity. Accuracy scores were obtained from all of the LAMP tests, but latency scores were computed only for those processing speed tasks that yielded high accuracy scores.

From the listing in Figure 1, it can be seen that a total of 25 test scores were available for the validation analyses (10 accuracy scores from the ASVAB, 9 accuracy scores from LAMP tests, and 6 latency scores from LAMP tests). There was interest in determining how the common factor structure of the ASVAB and LAMP tests correlated with the course criteria. Therefore six principal axis factors were extracted from the 25-variable intercorrelation matrix and rotated orthogonally using the Varimax method. The results of this factor analysis are presented in Appendix B. Six factors were identified, which were named (1) Processing Speed; (2) Working Memory; (3) Processing Accuracy; (4) Verbal; (5) Technical Knowledge; and (6) Numerical Facility/Perceptual Speed. Scores on these factors were correlated with accuracy and latency criteria from the logic gates course.

Correlation of Factor Scores with Learning Criteria

Accuracy Scores

Factor scores were computed for all subjects and correlated with accuracy and latency scores from the various problem blocks in the gates course. The results of these analyses are presented in Tables 4 and 5. Data in Table 4 clearly indicate that individual differences in the acquisition of declarative knowledge were highly associated with individual differences in working memory capacity. This association is not surprising, since the primary requirement of problem solving was to hold a set of complex rules in memory while processing information concerning the input-output signals of gate types. Errors could have been made either through memory failures concerning rules, or through the inaccurate execution of processing steps required in applying the rules. The working memory factor (WKMEM) scores correlated in the high 30's or low 40's with accuracy scores from the individual problem blocks, including both those without negations and those with negations. The reduction in the magnitude of relationships with the last few blocks of gate problems without negations could have been due to the ceiling effects mentioned previously. The Working Memory factor scores correlated .50 with an average accuracy score across all blocks involving gates without negations, .45 with an average across blocks involving gates with negations, and .53 with an average across all learning blocks.

The Processing Accuracy (PROCACC) factor scores had the second highest relationships with the gate-problem accuracy scores, the correlation coefficients generally running in the mid- to upper-.20's for individual learning blocks, and low .30's for block averages. The Verbal and Technical Knowledge factors had low but significant relationships with accuracy scores on blocks involving negations.

Table 4. Correlations of Factor Scores with Study 1 Course Accuracy Criteria

BLOCK	PROCSPD	WKMEM	PROACC	VERBAL	TECHKNOW	NUM/PS
1-1	.07	.42	.24	.12	.04	.13
1-2	.10	.43	.27	.09	.07	.09
1-3	.14	.43	.25	.07	.05	.03
1-4	.14	.40	.27	.02	.09	.05
1-5	.10	.39	.32	-.00	.04	.07
1-6	.07	.35	.30	.04	.06	.07
Av1	.12	.50	.33	.08	.07	.10
2-1	.08	.43	.25	.22	.20	.01
2-2	.05	.42	.28	.17	.17	.00
2-3	.08	.42	.26	.16	.17	-.02
2-4	.06	.41	.32	.12	.14	.02
Av2	.07	.45	.30	.18	.18	.00
AVG	.11	.53	.35	.15	.16	.06

Notes. Block codes are defined in Figure 2. PROCSPD = Processing Speed; WKMEM = Working Memory; PROACC = Processing Accuracy; TECHKNOW = Technical Knowledge; NUM/PS = Numerical Facility-Perceptual Speed.

Latency Scores

Data in Table 5 show the relationships of factor scores with median latency scores from the logic gates course. The highest validities were obtained from the Processing Speed factor. Significant relationships were also obtained between the Working Memory factor and latency criteria for the last four blocks of simple gates without negations. This correlation suggests that individuals with good working memory capacity had sufficient strength of declarative knowledge by this stage to facilitate the development of procedural skill.

Table 5. Correlations of Factor Scores with Study 1 Course Latency Criteria

BLOCK	PROCSPD	WKMEM	PROACC	VERBAL	TECHKNOW	NUM/PS
1-1	.24	.06	.18	.01	.00	-.13
1-2	.23	-.04	.05	-.08	.00	-.13
1-3	.25	-.16	.03	-.03	-.03	-.13
1-4	.33	-.15	.05	-.04	-.01	-.10
1-5	.31	-.19	.00	-.04	-.04	-.12
1-6	.35	-.18	.04	-.02	-.02	-.13
Av1	.34	-.12	.06	-.04	-.01	-.14
2-1	.29	.07	.17	.00	-.01	-.17
2-2	.32	.01	.14	.01	.04	-.18
2-3	.32	.02	.05	-.02	.02	-.18
2-4	.34	.05	.10	.06	.03	-.20
Av2	.35	.05	.13	.02	.02	-.19
AVG	.35	-.04	.12	-.02	.01	-.18

Notes. Block codes are defined in Figure 2.

Significant relationships were also found between the Numerical Facility/Perceptual Speed factor and gates-course latency criteria. However, in a subsequent analysis, it was revealed that all of these relationships were accounted for by the LAMP Number Fact Retrieval test. Neither the ASVAB Numerical Operations test nor the Coding Speed test contributed to the prediction of latency criteria.

Comparative Validities of ASVAB and LAMP Tests for Gates-Course Learning Criteria.

A primary goal of the present set of studies was to determine whether LAMP tests would do as well or better than conventional paper-and-pencil tests in predicting meaningful learning criteria. Of course, the present studies were limited to learning in a single content area--that of electronic logic gates. Moreover, time permitted only a small sample of LAMP tests to be administered and validated. Nevertheless, results from the present research will add to an accumulation of evidence to be used to evaluate LAMP tests.

In the logic gates task, two types of criterion data were considered. The first plausibly reflected individual differences in the acquisition of declarative knowledge and was indexed by the **accuracy** of specifying the outputs of logic gates. The second criterion reflected the acquisition of procedural skill, and was indexed by the **time required** for the subjects to correctly analyze and solve the logic gates problems. Each of these aspects of the criterion was treated separately in the following analyses.

Acquisition of Declarative Knowledge

The percent correct score for any one block of gate problems indicated the level of declarative knowledge for a subject at that stage of learning. Thus, it was desirable to relate ASVAB and LAMP tests to accuracy scores separately for each of the six blocks of gates without negations and for each of the four blocks with negations. There were two problems with this approach. First, as more and more individuals reach a level of perfect accuracy, the obtained validities suffered from a restriction in range due to ceiling effects. Second, individual block scores were based on a small number of problems, and were therefore somewhat unreliable. For this reason, the average latency across each series of blocks was also included as a criterion.

Two approaches were taken to test validation. Both involved computing differences in full- and restricted-model R^2s. The initial step in the **Approach 1** analysis was to include all ASVAB and LAMP tests in a single multiple regression equation to predict each criterion. The squares of these multiple correlations (R^2s) reflected the amount of criterion variance accounted for by the combined test battery. Then the LAMP tests were removed from the equations to determine the losses in criterion variance accounted for. In each instance, the loss in R^2 indicated the unique contribution of the LAMP tests to the ASVAB tests in accounting for criterion variance. Next, the ASVAB tests were removed from the full equation to determine their unique contribution to LAMP tests in accounting for criterion variance. In both instances, the significance levels of R^2 losses were computed. The results from these analyses are reported in Table 6.

Table 6. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 1 Accuracy Criteria, Estimated by Approach 1

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.024	1.397	.179	.131	5.103	.000	.528	.279
1-2	.017	.997	.445	.153	6.037	.000	.535	.287
1-3	.010	.600	.814	.180	7.117	.000	.539	.290
1-4	.016	.904	.530	.168	6.507	.000	.525	.275
1-5	.022	1.371	.191	.210	8.667	.000	.565	.319
1-6	.006	.345	.968	.186	7.197	.000	.521	.272
Av1	.017	1.153	.321	.222	10.319	.000	.628	.394
2-1	.065	4.269	.000	.133	5.809	.000	.596	.356
2-2	.036	2.264	.014	.155	6.421	.000	.567	.321
2-3	.034	2.184	.018	.174	7.370	.000	.579	.336
2-4	.025	1.562	.115	.192	8.071	.000	.574	.329
Av2	.044	3.008	.001	.182	8.267	.000	.617	.381
AVG	.035	2.763	.003	.236	12.412	.000	.682	.465

Notes: Block codes are defined in Figure 2. See text for explanation of Approach 1.

The combination of LAMP and ASVAB tests did a reasonably good job of predicting individual differences in learning efficiency, the obtained multiple correlations ranging from the low to the high .50's for the various learning blocks. The multiple correlations for an average across blocks without negations was .628, for blocks with negations was .617, and for all blocks combined was .682 (46.5 percent of the criterion variance being accounted for). Tests from the ASVAB did not add significantly to LAMP tests in predicting accuracy scores on logic gates without negations, and added very little to the LAMP tests in predicting learning on gates with negations. On the other hand, LAMP tests uniquely accounted for an additional 22.2% of the criterion variance for gates without negations, 18.2% for gates with negations, and 23.6% for an average across all the problem blocks.

The significance levels associated with losses in R^2s reported in Table 6 should be trustworthy, since appropriate degrees of freedom were used in the computations of F-ratios. However, the estimated unique contributions, which were determined by subtracting restricted-model R^2s from full-model R^2s, were likely to be somewhat inaccurate because of the varying number of independent variables in the equations. Other factors held constant, the larger the number of independent variables in an equation, the more likely the computed R^2 will be an overestimate of the population parameter. Since the ASVAB equations contained only ten independent variables, while the LAMP equations contained fifteen, there was a greater opportunity for capitalization on chance relationships in the LAMP equations. There was even a greater opportunity for capitalization on chance relationships in the full-model, which contained 25 independent variables. To ameliorate these circumstances, **Approach 2** was taken, in which unique contributions were estimated using differences in R^2s which had been adjusted for the number of independent variables to more closely approximate the population parameters.[4] The results of the Approach 2 analyses are reported in Table 7.

Table 7 reports the Rs and *adjusted* R^2s for ASVAB tests alone, for LAMP tests alone, and for a combination of LAMP and ASVAB tests for the various gates-course accuracy criteria. The last column indicates the unique contribution of LAMP tests to the ASVAB in accounting for criterion variance.[5] These values are based upon differences in the full- and restricted-model *adjusted* R^2s, and therefore should be closer to the population parameters. They indicate that the LAMP tests added 20.5% unique variance to ASVAB in accounting for average accuracy scores across gate problems

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[4]A sample R^2 usually does not fit the population as well as it fits the computing sample. The following equation was applied to adjust the R^2 to more closely reflect the goodness of fit of the model in the population: $R^2_a = R^2 - (p(1-R^2))/(N-p-1)$, where p is the number of independent variables in the equation.

[5]In this, as well as in succeeding tables, LAMP/ASVAB and ASVAB/LAMP represent the contributions of LAMP to ASVAB and ASVAB to LAMP, respectively.

without negations, 16.3% in accounting for average accuracy scores across gate problems with negations, and 22.2% in accounting for average accuracy scores across all ten problem blocks.

While the LAMP tests contributed substantially to ASVAB tests in accounting for the individual differences in declarative learning as reflected in the accuracy scores, the data indicate that ASVAB tests added nothing to the LAMP tests in predicting performance on the test blocks without negations, and very little to the LAMP tests in predicting performance on the test blocks with negations.

Table 7. Unique Contributions of ASVAB and LAMP tests to the Prediction of Study 1 Accuracy Criteria, Estimated by Approach 2

	FULL MODEL		LAMP		ASVAB		LAMP/	ASVAB/
BLOCK	R	ADJ R^2	R	ADJ R^2	R	ADJ R^2	ASVAB	LAMP
1-1	.528	.236	.504	.229	.385	.129	.107	.007
1-2	.535	.244	.519	.244	.366	.114	.130	.000
1-3	.539	.248	.529	.255	.332	.090	.158	-.007
1-4	.525	.232	.509	.234	.328	.087	.175	-.002
1-5	.565	.279	.545	.272	.330	.089	.190	.007
1-6	.521	.229	.516	.240	.293	.065	.164	-.011
Av1	.628	.358	.614	.356	.415	.153	.205	.002
2-1	.596	.317	.539	.266	.412	.205	.112	.051
2-2	.567	.281	.534	.260	.408	.149	.132	.021
2-3	.579	.296	.549	.277	.402	.143	.153	.019
2-4	.574	.290	.552	.280	.370	.117	.173	.010
Av2	.617	.344	.580	.314	.446	.181	.163	.030
AVG	.681	.433	.656	.410	.478	.211	.222	.023

Notes. In those instances in which the adjusted R^2 for the LAMP tests is higher than that for the FULL MODEL, the estimated contribution for the ASVAB tests is negative. This is an artifact of the estimation procedure. Block codes are defined in Figure 2. See text for explanation of Approach 2.

Acquisition of Procedural Skill

In most instructional settings, the development of procedural skill tends to follow the acquisition of declarative knowledge. In the present study, individuals first learned the rules for analyzing the input signals for logic gates in order to correctly specify their output signals. With practice in applying these rules, they were able to increase the speed of this analysis and decision activity. Thus, the development of procedural skill was reflected in the latency scores. Table 8 reports the results of an analysis to determine the unique contributions of LAMP and ASVAB tests in accounting for variance in these scores. It is similar to the Approach 1 data presented in Table 6 for accuracy scores. The multiple correlations are for the full model, using a combination of all ASVAB and LAMP tests, while the other columns present the unique contributions of ASVAB to LAMP tests and LAMP tests to ASVAB in accounting for the criterion variance. The F-ratios and significance levels are reasonable population estimates, since they were computed using appropriate degrees-of-freedom values.

Table 8. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 1 Latency Criteria, Estimated by Approach 1

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.021	1.13	.339	.167	5.847	.000	.443	.197
1-2	.009	.452	.920	.108	3.542	.000	.272	.138
1-3	.011	.539	.863	.104	3.413	.000	.379	.144
1-4	.008	.430	.932	.154	5.298	.000	.428	.184
1-5	.014	.723	.703	.147	5.095	.000	.436	.190
1-6	.014	.763	.665	.186	6.724	.000	.470	.221
Av1	.009	.493	..895	.167	5.897	.000	.449	.201
2-1	.005	.303	.980	.229	8.482	.000	.490	.240
2-2	.012	.652	.769	.225	8.396	.000	.495	.245
2-3	.009	.462	.914	.199	7.156	.000	.468	.219
2-4	.016	.887	.545	.207	7.727	.000	.498	.248
Av2	.010	.597	,817	.247	9.488	.000	.518	.268
AVG	.006	.324	.975	.220	8.192	.000	.496	.246

Notes: See text for explanation of Approach 1. Block codes defined in Figure 2.

The data in Table 8 indicate that the ASVAB tests added nothing to the LAMP test in predicting the development of procedural skill. This was to be expected, since the ASVAB tests were designed to predict technical school grades, which are primarily a reflection of declarative knowledge acquisition. On the other hand, the LAMP tests added 16.7% unique variance to the ASVAB tests in predicting average latency scores on gates without negations, 24.7% in predicting the average on gates with negations, and 22.0% in predicting the average across all gate blocks.

Again, these estimates are somewhat inaccurate because of the varying numbers of independent variables included the equations. Therefore, an Approach 2 analysis, based on adjusted R^2s, is reported in Table 9.

Table 9. Unique Contributions of ASVAB and LAMP tests to the Prediction of Study 1 Latency Criteria, Estimated by Approach 2.

	FULL MODEL		LAMP		ASVAB		LAMP/	ASVAB/
BLOCK	R	ADJ R^2	R	ADJ R^2	R	ADJ R^2	ASVAB	LAMP
1-1	.443	.149	.418	.146	.172	.007	.142	.015
1-2	.372	.087	.359	.099	.173	.008	.079	-.012
1-3	.379	.093	.364	.103	.199	.018	.075	-.010
1-4	.428	.135	.419	.147	.172	.008	.127	-.012
1-5	,436	.142	.420	.147	.208	.021	.121	-.005
1-6	.470	.174	.454	.179	.185	.012	.162	-.005
Av1	.449	.154	.438	.164	.184	.012	.142	-.010
2-1	.490	.195	.455	.208	.105	-.011	.206	-.013
2-2	.495	.200	.483	.206	.139	-.003	.203	-.006
2-3	.468	.173	.459	.183	.144	-.002	.175	-.010
2-4	.498	.203	.482	.205	.203	.019	.184	.002
Av2	.518	.225	.508	.232	.147	-.007	.232	-.007
AVG	.496	.201	.490	.213	.169	.004	.197	-.012

Notes. In those instances in which the adjusted R^2 for the LAMP tests is higher than that for the FULL MODEL, the estimated contribution for the ASVAB tests is negative. Block codes are defined in Figure 2. See text for explanation of Approach 2.

The Approach 2 data in Table 9 tell essentially the same story. The ASVAB tests did not contribute to the LAMP tests in accounting for the latency criteria. As a matter of fact, in most instances the estimated unique contribution of ASVAB tests was a negative value (due to imperfections in out estimation procedures) which occurred when the adjusted R^2 for the LAMP tests was higher than that for the FULL MODEL. On the other hand, the LAMP tests added substantially to ASVAB tests in predicting these criteria. The LAMP contributions were estimated to be 14.2% for an average across gates without negations, 23.2% for an average across gates with negations, and 19.7% across all gate blocks.

As mentioned previously, procedural skill in this study was reflected in the time required for subjects to analyze the input signals of logic gates and correctly determine their output signals. However, in Block 1 some individuals made a number of errors in specifying output signals, indicating that their understanding of the rules was weak at that stage. The meaning of latency scores is unclear when accuracy is low, and such scores are likely to be unpredictable by ability factors. In a sense, they introduced a type of 'error variance' in the criterion scores. This problem becomes less and less pronounced in the later blocks, in which most responses were correct.

One approach to clarifying latency data is to discard subjects who do not achieve some minimum level of declarative knowledge during the course. This procedure tends to purify the latency scores as a skill acquisition criterion. In the present study, subjects were eliminated who did not achieve at least a 90% accuracy level in the fourth block of gates without negations. Thus, 104 subjects, were eliminated, leaving 344 subjects in the residual sample. The average accuracy levels for these 344 subjects across the six blocks of gates without negations was 81.8%, 90.6%, 94.2%, 96.4%, 96.6%, and 96.9%, respectively, and 86.5%, 90.0%, 92.3%, and 92.5% for the gates with negations, respectively. Tables 10 and 11 report data comparable to that reported in Tables 8 and 9, except that they are based on subjects in the residual sample.

The multiple correlations in Table 10 are higher than they were in Table 8, since there was less variance associated with incorrect responses in the residual sample data. However, the conclusions based upon these results are the same. The ASVAB tests added nothing to LAMP tests in accounting for procedural skill development as reflected in the latency data. On the other hand, LAMP tests added considerable variance to the ASVAB tests in accounting for procedural skill development. The unique contribution of LAMP tests was estimated to be 22.8% for an average across the blocks of gates without negations, 24.2% for an average across blocks with negations, and 24.0% for an average across all blocks.

The data in Table 11 represent similar findings, except that the estimated LAMP contribution levels are slightly lower, being 16.5% for the blocks without negations, 21.7% for the blocks with negations, and 21.3% across all blocks.

Table 10. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 1 Latency Criteria, Estimated by Approach 1 in the Residual Sample (N=344)

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.044	1.815	.057	.193	5.356	.000	.486	.236
1-2	.032	1.324	.216	.138	3.756	.000	.469	.220
1-3	.018	.744	.682	.163	4.555	.000	.489	.239
1-4	.010	.409	.942	.210	6.005	.000	.508	.258
1-5	.014	.636	.783	.212	6.293	.000	.534	.285
1-6	.014	.630	.788	.243	7.298	.000	.542	.239
Av1	.018	.842	.589	.228	6.939	.000	.550	.303
2-1	.019	.811	.618	.216	6.286	.000	.522	.272
2-2	.010	.447	.923	.217	6.402	.000	.531	.282
2-3	.011	.467	.911	.193	5.475	.000	.504	.254
2-4	.020	.927	.509	.231	7.009	.000	.550	.302
Av2	.017	.798	.630	.242	7.500	.000	.561	.315
AVG	.019	.879	.553	.240	7.375	.000	.558	.311

Notes: See text for explanation of Approach 1. Block codes are defined in Figure 2.

Table 11. Unique Contributions of ASVAB and LAMP tests to the Prediction of Study 1 Latency Criteria, Estimated by Approach 2 in the Residual Sample (N = 344)

	FULL MODEL		LAMP		ASVAB		LAMP/	ASVAB/
BLOCK	R	ADJ R^2	R	ADJ R^2	R	ADJ R^2	ASVAB	LAMP
1-1	.486	.176	.439	.156	.208	.015	.161	.020
1-2	.469	.159	.433	.150	.286	.082	.077	.009
1-3	.489	.179	.470	.186	.275	.048	.131	-.007
1-4	.508	.200	.498	.214	.219	.019	.181	-.014
1-5	.534	.229	.501	.238	.271	.045	.184	-.014
1-6	.542	.239	.529	.247	.226	.023	.216	-.008
Av1	.550	.212	.533	.252	.273	.047	.165	-.040
2-1	.522	.215	.503	.220	.238	.028	.187	-.005
2-2	.531	.226	.521	.239	.255	.037	.188	-.013
2-3	.504	.196	.493	.209	.248	.033	.163	-.013
2-4	.550	.247	.531	.249	.267	.043	..204	-.002
Av2	.561	.261	.546	.266	.270	.044	.217	-.005
AVG	.558	.257	.540	.260	.268	.044	.213	.018

Notes. In those instances in which the adjusted R^2 for the LAMP tests is higher than that for the FULL MODEL, the estimated contribution for the ASVAB tests is negative. Block codes are defined in Figure 2. See text for explanation of Approach 2.

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STUDY 2

Study 2 involved several modifications of the gates course and in the LAMP tests selected for validation. To provide a longer practice period for the subjects to improve their procedural skills, the course was modified to include eight blocks of gates without negations instead of only six. In addition, complex gate circuit problems were included to increase job relevance. The inclusion of more learning blocks reduced the time available for predictor test administration, so the Number Fact Retrieval, Meaning Identity, 123 Number Reduction, and Digit Span tests were dropped in order to increase the number of non-quantitative tests defining the working memory factor; to include measures of spatial abilities and associative learning abilities, four new tests were added: General Knowledge, Word Association, Figure Recognition, and Mental Character Generation. Finally, a pretest of 'going-in' knowledge was administered to subjects. This pretest was made up from problems selected from the course to follow. To decrease the probability of subjects recording the correct answers by chance, six incorrect but plausible question alternatives (foils) were generated and included as possible answers to each question. Scores from this pretest were at chance level (M=14.6, S.D.=12.1), and they did not correlate significantly with any of the accuracy or latency blocks in Study 2. It was concluded that the course represented a relatively novel learning situation to the subjects.

Table 12 reports the mean percent correct and the mean latency scores for the eight blocks of simple gates without negations and for averages across blocks in other sections of the course. The development of procedural skill is clearly reflected in the systematic reduction of response times across the eight blocks of simple gates without negations; the mean of median latencies dropped from 2.21 seconds in Block 1 to 1.23 seconds in Block 8, with a corresponding drop in standard deviations from .69 seconds in Block 1 to .32 seconds in Block 8.

The percent correct scores also reflect a systematic strengthening of declarative knowledge across these same blocks, with the means increasing from 83.7 in Block 1 to 97.4 in Block 8. There was an increasing restriction in range due to ceiling effects, which was more serious than that encountered in Study 1. By the 8th block, 50% of the subjects made perfect scores, and another 29% missed only one problem. The standard deviation of the scores in Block 8 was only 4.0%. The effect of the ceiling effect was to render the later blocks less valuable as measures of individual differences in knowledge acquisition. At the same time, since most subjects made perfect or near perfect scores in the later blocks, the latency scores in these blocks were wellsuited as indicators of their level of procedural skill.

Table 12. Means and Standard Deviations for Study 2 Blocks And Averages

	ACCURACY		LATENCY	
	MEANS	S.D.'s	MEANS	S.D's
1-1	83.67	11.62	2.21	.69
1-2	89.15	11.23	1.83	.55
1-3	92.66	9.40	1.63	.56
1-4	95.02	7.19	1.46	.48
1-5	95.86	5.80	1.34	.42
1-6	96.12	5.75	1.32	.38
1-7	96.83	4.73	1.25	.36
1-8	97.35	4.02	1.23	.32
Av1	93.33	6.06	1.46	.38
2-1	87.25	14.91	3.33	.80
Av3	91.47	9.94	2.30	.61
Av4	89.13	11.79	3.47	1.06
AVG	91.51	7.89	2.01	.46

Notes. Block codes are defined in Figure 2.

Factor Analysis

In a factor analysis of the predictor tests, six principal axis factors were extracted and rotated using the Varimax method. The results of this analysis are reported in Appendix B.

The six factors were given the same names as the six factors identified in Study 1. They were essentially equivalent, except for the Working Memory factor, which was now defined by verbal and spatial tests as well as by quantitative tests, and for the Processing Speed factor, which was a little weaker because the Meaning Identity test had been dropped from the battery. Also, the Numerical Facility/Perceptual Speed factor contained less numerical variance because of the omission of the Number Fact Retrieval test. The correlations between factor scores and the various gates course accuracy criteria are presented in Table 13, while those for the course latency criteria are presented in Table 14.

Table 13. Correlations of Factor Scores with Study 2 Accuracy Criteria

BLK	VERBAL	WKMEM	PROCSPD	PROCACC	TECHKNOW	NUM_PS
1-1	.15	.53	-.09	.22	.05	.14
1-2	.12	.50	-.08	.25	.07	.11
1-3	.04	.50	-.07	.24	.01	.10
1-4	.06	.45	-.08	.24	.04	.08
1-5	.01	.37	-.09	.23	.10	.11
1-6	.03	.31	-.01	.21	-.01	.09
1-7	-.01	.28	-.06	.18	-.04	.09
1-8	-.02	.26	-.09	.21	-.08	.12
Av1	.08	.53	-.09	.28	.03	.13
2-1	.14	.43	-.05	.22	.17	.12
Av3	.15	.49	-.11	.28	.12	.05
AVG	.15	.54	-.11	.30	.12	.11

Notes. Block codes are defined in Figure 2.

The criteria in these, as well as in later tables, include eight blocks of simple gates without negations, an average across these eight blocks, a single block of simple gates with negations, an average for the two blocks of mixed simple gates (with and without negations), an average across the three blocks of mixed simple gates and complex gate circuits (with and without negations), and, finally, an average across all of the course blocks.

Data in Table 14 reveal that the Working Memory factor scores had highest relationships with all of the accuracy criterion variables, which is consistent with the findings in Study 1. It should be noted, however, that the magnitude of the relationships dropped systematically from Block 1 to Block 8 of simple gates without negations. This downturn was expected, and is attributed to the decreasing individual differences variance due to ceiling effects. The correlation of the Working Memory factor scores with an average across all blocks of simple gates without negations was .530, and was .543 for an average across all blocks in the course.

Table 14. Correlations of Factor Scores with Study 2 Latency Criteria

BLK	VERBAL	WKMEM	PROCSPD	PROCACC	TECHKNOW	NUM_PS
1-1-	-.09	.09	.19	.10	-.06	-.09
1-2	-.17	-.14	.28	.02	-.12	-.14
1-3	-.15	-.28	.30	-.03	-.06	-.12
1-4	-.11	-.28	.27	-.05	-.05	-.10
1-5	-.12	-.34	.31	-.07	-.09	-.07
1-6	-.12	-.30	.40	-.06	-.07	-.10
1-7	-.14	-.32	.35	-.04	-.06	-.14
1-8	-.16	-.30	.37	-.02	-.05	-.12
Av1	-.15	-.29	.39	-.02	-.07	-.13
2-1	-.09	-.15	.26	.10	-.11	-.13
Av3	-.14	-.11	.35	.11	-.05	-.15
Av4	-.08	.09	.21	.14	-.02	-.21
AVG	-.16	-.13	.36	.09	-.06	-.16

Notes. Block codes are defined in Figure 2.

Again consistent with the findings in Study 1, the Processing Accuracy factor scores had the second highest relationships with accuracy scores from the gates course. The Numerical Facility/Perceptual Speed, Verbal and Technical Knowledge factor scores had low but significant relationships with scattered test blocks, correlating -.110, .145, and .117, respectively, with the average accuracy across all course blocks. The data in Table 14 show that the Processing Speed factor scores had the highest relationships with the latency criteria, again consistent with the findings in Study 1. The Working Memory factor scores were particularly strong in predicting latencies in the later blocks of simple gates without negations, thus replicating another finding in Study 1. This finding is consistent with the hypothesis that individuals with high working-memory capacity attained sufficient strength in declarative knowledge in the early blocks to facilitate their development of procedural skill. The Numerical Facility/Perceptual Speed and the Verbal factor scores also had scattered relationships with latency criteria, attaining correlations of -.160 and -.155 respectively with the average latency across all blocks.

In summary, the results of the factor analysis in Study 2 were remarkably similar to those obtained in Study 1, in spite of changes in the criterion and predictor variables. The same number of factors was obtained in both studies, and the patterns of factor-criterion relationships were highly similar.

Comparative Validities of ASVAB and LAMP Tests for Gates-Course Learning Criteria

Acquisition of Declarative Knowledge

As was the case in Study 1, the accuracy scores from the gates-course test blocks were accepted as indicators of acquired declarative knowledge. The same two approaches were taken to determine the ability of LAMP tests alone, ASVAB tests alone, and a combination of LAMP and ASVAB tests to predict these scores. In Approach 1, the losses in R^2s were determined as LAMP tests and ASVAB tests were removed one set-at-a-time from full models containing both classes of predictors. In each instance, the unique contribution of the two predictor sets were computed, along with F-ratios and significance levels based on appropriate degrees of freedom. The results from this first analysis are reported in Table 15.

Table 15. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 2 Accuracy Criteria, Estimated by Approach 1

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.043	2.764	.003	.155	7.166	.000	.611	.373
1-2	.039	2.376	.010	.146	6.428	.000	.585	.342
1-3	.051	3.047	.001	.158	6.683	.000	.561	.315
1-4	.042	2.394	.009	.152	6.214	.000	.541	.293
1-5	.022	1.163	.314	.127	4.742	.000	.474	.224
1-6	.025	1.243	.261	.105	3.699	.000	.422	.178
1-7	.028	1.372	.191	.091	3.163	.000	.404	.163
1-8	.039	1.921	.041	.094	3.315	.000	.418	.175
Av1	.042	2.770	.003	.189	8.929	.000	.622	.387
2-1	.053	3.120	.000	.120	5.017	.000	.553	.305
Av3	.055	3.310	.000	.136	5.901	.000	.575	.330
Av4	.016	1.035	.413	.240	11.432	.000	.625	.391
AVG	.031	2.215	.016	.222	11.393	.000	.659	.434

Notes: Block codes defined in Figure 2. See text for explanation of Approach 1.

In Approach 2, multiple correlations were computed for the LAMP tests alone, the ASVAB tests alone, and for a combination of LAMP and ASVAB tests against the various accuracy criteria. The unique contribution of each battery to the other was estimated by the differences in R^2s computed in the restricted and full models, after such R^2s had been adjusted for the number of independent variables to be more accurate estimates of population parameters. The results of this second analysis are reported in Table 16.

Table 16. Unique Contributions of ASVAB and LAMP tests to the Prediciton of Study 2 Accuracy Criteria, Estimated by Approach 2

	FULL MODEL		LAMP		ASVAB		LAMP/	ASVAB/
BLOCK	R	ADJ R^2	R	ADJ R^2	R	ADJ R^2	ASVAB	LAMP
1-1	.611	.336	.575	.308	.476	.200	.136	.028
1-2	.585	.303	.551	.280	.443	.177	.126	.023
1-3	.561	.274	.513	.238	.396	.136	.138	.036
1-4	.541	.251	.501	.226	.376	.121	.130	.025
1-5	.474	.179	.450	.175	.312	.076	.103	.004
1-6	.422	.130	.391	.124	.271	.051	.079	.006
1-7	.404	.114	.376	.106	.268	.050	.064	.008
1-8	.418	.126	.369	.107	.284	.059	.089	.019
Av1	.622	.351	.588	.324	.446	.180	.171	.027
2-1	.553	.264	.502	.227	.430	.166	.098	.037
Av3	.575	.291	.525	.231	.441	.175	.116	.040
Av4	.625	.355	.612	.354	.388	.130	.225	.001
AVG	.659	.400	.635	.383	.460	.193	.207	.017

Notes. Block codes are defined in Figure 2. See text for explanation of Approach 2.

The impact of the ceiling effects on the eight blocks of simple gates without negations is reflected in Tables 15 and 16 by a systematic reduction in the magnitudes of the full-model Rs from .611 in Block 1 to .418 in Block 8. The unique contribution of ASVAB to LAMP tests in the prediction of these criteria was small, and in some instances not significant. On the other hand, the LAMP tests contributed significantly to the ASVAB tests in predicting all blocks in the course, including the blocks of simple gates. In spite of the ceiling effects, the estimated contribution of LAMP to ASVAB tests in predicting average accuracy across the first eight blocks was estimated to be 18.9% by Approach 1 (Table 15) and 17.1% by Approach 2 (Table 16). The LAMP tests were particularly powerful in predicting average accuracy scores across the blocks which contained complex gate circuits, yielding a multiple correlation of .612 compared with .388 for the ASVAB tests. In this instance, the unique contribution of the LAMP tests to ASVAB was estimated to be 24.0% by Approach 1, and 22.5% by Approach 2. The unique contribution of ASVAB tests to LAMP tests was estimated to be non-significant (F-ratio = 1.035, P> .4). The multiple correlation of the LAMP tests with average accuracy across the entire course was .635, compared with .460 for the ASVAB tests, and the unique contribution of LAMP tests to ASVAB was estimated to be 22.2% by Approach 1 and 20.7% by Approach 2. These estimates are to be compared with the 3.1% and 1.7% estimates of the contribution of ASVAB tests to LAMP tests, which were not significant at the .01 level. All of these values are remarkably similar to those obtained in Study 1.

Acquisition of Procedural Skill

As in Study 1, latency scores were used as indicants of procedural skill. Once individuals had the rules for solving gate problems firmly in mind, they tended to accurately apply them with increasing speed and efficiency. For most individuals, proceduralization of rules began even before they reached the Block 1 problem set. Some individuals made perfect scores on all problems in this block, and solved each problem with increased speed. Others were relatively accurate on AND or OR gates, but were still somewhat confused and inaccurate in solving NOR gates. The increase in accuracy from Block 1 to Block 8 reflected the continued acquisition and strengthening of declarative knowledge (concerning gate rules) within the subject sample, and by the 8th block, a 97% accuracy level was obtained. Latency scores were the best measures of individual differences in procedural skill at any learning stage, but this criterion was contaminated to the extent that declarative learning had not been achieved. For this reason, the latency scores in Study 2 were analyzed in the same manner as they were in Study 1. First, they were analyzed in the full sample, using the same two approaches as were used for analyzing accuracy scores. The results of these analyses are reported in Tables 17 and 18. Then they were analyzed on a subsample of individuals who reached the 90% accuracy level by the 4th block of simple gates without negations. The results of these analyses are presented in Tables 19 and 20.

Table 17. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 2 Latency Criteria, Estimated by Approach 1

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.039	1.867	.048	.097	3.272	.000	.380	.145
1-2	.024	1.202	.288	.131	4.754	.000	.450	.203
1-3	.014	.744	.673	.152	5.821	.000	.490	.240
1-4	.024	1.231	.269	.135	4.950	.000	.457	.209
1-5	.028	1.607	.102	.194	7.842	.000	.530	.281
1-6	.022	1.251	.256	.213	8.823	.000	.547	.301
1-7	.012	.668	.754	.172	6.827	.000	.517	.267
1-8	.011	.620	.796	.182	7.261	.000	.522	.272
Av1	.019	1.001	.361	.205	8.421	.000	.542	.294
2-1	.025	1.249	.258	.143	5.188	.000	.448	.201
Av3	.022	1.169	.310	.171	6.486	.000	.487	.237
Av4	.017	.945	.491	.214	8.334	.000	.505	.256
AVG	.020	1.113	.350	.206	8.260	.000	.526	.277

Notes: Block codes defined in Figure 2. See text for explanation of Approach 1.

The results reported in Tables 17 and 18 are comparable to those obtained in Study 1. In no instance did the ASVAB tests add unique valid variance (at the .01 level) to the LAMP tests in predicting latency scores. On the other hand, the unique contribution of LAMP tests to ASVAB in predicting the average latency on simple gates without negations was estimated by the two approaches to be 20.5% and 18.4%, respectively. The multiple correlation of LAMP tests for the average latency scores across all gate blocks was .507, compared with .267 for ASVAB tests, and the Approach 1-Approach 2 estimates of the unique contribution of LAMP tests to ASVAB tests in predicting this criterion were 20.6% and 18.5%, respectively.

Table 18. Unique Contributions of ASVAB and LAMP tests to the Prediction o. Study 2 Latency Criteria, Estimated by Approach 2

BLOCK	FULL MODEL R	FULL MODEL ADJ R^2	LAMP R	LAMP ADJ R^2	ASVAB R	ASVAB ADJ R^2	LAMP/ ASVAB	ASVAB/ LAMP
1-1	.380	.094	.324	.075	.219	.025	.069	.019
1-2	.450	.156	.423	.151	.268	.050	.106	.005
1-3	.490	.196	.476	.200	.297	.066	.130	-.004
1-4	.457	.162	.430	.157	.272	.052	.110	.005
1-5	.530	.239	.503	.228	.295	.065	.174	.011
1-6	.549	.260	.529	.255	.297	.067	.193	.005
1-7	.517	.224	.505	.230	.308	.073	.151	-.006
1-8	.522	.229	.511	.236	.300	.069	.160	-.007
Av1	.542	.252	.524	.251	.298	.068	.184	.001
2-1	.448	.154	.420	.149	.241	.036	.118	.005
Av3	.487	.192	.464	.189	.259	.045	.147	.003
Av4	.505	.212	.488	.213	.205	.019	.167	-.001
AVG	.526	.234	.507	.232	.267	.049	.185	.002

Notes. In those instances in which the adjusted R^2 for the LAMP tests is higher than that for the FULL MODEL, the estimated contribution for the ASVAB tests is negative. Block codes are defined in Figure 2. See text for explanation of Approach 2.

Discarding subjects who did not reach the 90% accuracy level by the 4th block of simple gates without negations resulted in a loss of only 63 subjects, or 14.6% of the original sample. However, this smaller sample resulted in criterion measures which were considerably less contaminated by inaccurate responses. By the 4th block of simple gates without negations, the average percent correct score was over 97%, and this average rose to above the 98% level by the 8th block. Furthermore, in none of blocks of the more complex gates, which followed, did the average accuracy level fall below the 90% level.

As expected, the full-model multiple correlations were higher in the residual sample, rising from .404 in Block 1 of simple gates without negations to .549 in Block 8. The full-model multiple correlation was .569 for an average across the eight blocks without negations, and .572 for an average across all course blocks. Again, the data in Tables 19 and 20 indicate that the ASVAB tests did not add significantly to the LAMP tests in predicting any of the latency criteria. On the other hand, using the two approaches previous described, the estimated contribution of LAMP tests to ASVAB tests was

21.8% and 19.6% for predicting the average latency across simple gates without negations, and 21.9% and 19.7% for the average latency across all course blocks.

Table 19. Unique Contributions of ASVAB and LAMP Tests to the Prediction of Study 2 Latency Criteria, Estimated by Approach 1 in the Residual Sample (N=368)

	ASVAB ADDS TO LAMP			LAMP ADDS TO ASVAB			FULL-MODEL	
BLK	R^2	F	SIGN.	R^2	F	SIGN.	R	R^2
1-1	.036	1.505	.136	.111	3.257	000	.404	.163
1-2	.028	1.312	.222	.148	4.908	.000	.511	.261
1-3	.027	1.282	.239	.159	5.384	.000	.524	.274
1-4	.031	1.425	.167	.162	5.360	.000	.508	.258
1-5	.026	1.291	.234	.204	7.111	.000	.547	.299
1-6	.027	1.341	.207	.206	7.266	.000	.553	.306
1-7	.011	.499	.890	.182	6.137	.000	.525	.275
1-8	.012	.567	.841	.194	6.803	.000	.549	.302
Av1	.023	1.149	.325	.218	7.893	.000	.569	.324
2-1	.019	.910	.524	.198	6.774	.000	.530	.281
Av3	.017	.874	.558	.211	7.735	.000	.577	.333
Av4	.019	.892	.541	.188	6.433	.000	.531	.282
AVG	.018	.908	.525	.219	7.953	.000	.572	.327

Notes: Block codes are defined in Figure 2. See text for explanation of Approach 1.

Discussion

All in all, the results from Study 2 were very similar to those obtained in Study 1. The ASVAB tests were found to be poor predictors of latency scores in both studies, and they added nothing to the LAMP tests in predicting such criteria. This result was not unexpected, since the ASVAB was designed to predict technical school grades and has historically been validated against grade criteria. On the other hand the LAMP tests produced a multiple correlation of .490 in Study 1 and .507 in Study 2 in predicting the average latency scores in the full samples. When the samples were residualized to include only those subjects who had accuracy scores of at least 90% on Block 4 of simple gates without negations, the multiple correlations were computed to be .558 in Study 1 and .572 in study 2.

Table 20. Unique Contributions of ASVAB and LAMP tests to the Prediction of Study 2 Latency Criteria, Estimated by Approach 2 in the Residual Sample (N = 368)

	FULL MODEL		LAMP		ASVAB		LAMP/	ASVAB/
BLOCK	R	ADJ R^2	R	ADJ R^2	R	ADJ R^2	ASVAB	LAMP
1-1	.404	.105	.356	.092	.229	.026	.079	.013
1-2	.511	.209	.482	.202	.336	.088	.077	.007
1-3	.524	.224	.497	.217	.339	.090	.134	.007
1-4	.508	.206	.476	.196	.309	.070	.136	.010
1-5	.547	.250	.522	.244	.309	.070	.179	.006
1-6	.553	.258	.528	.250	.317	.075	.183	.008
1-7	.525	.224	.514	.235	.306	.068	.156	-.011
1-8	.549	.253	.539	.262	.329	.083	.170	-.009
Av1	.569	.277	.549	.274	.326	.081	.196	.003
2-1	.530	.231	.512	.232	.288	.057	.174	-.001
Av3	.577	.286	.562	.289	.350	.098	.188	-.063
Av4	.531	.232	.513	.234	.306	.068	.164	-.004
AVG	.572	.280	.556	.282	.329	.083	.197	-.002

Notes. In those instances in which the R^2 for the LAMP tests is higher than that for the FULL MODEL, the estimated contribution for the ASVAB tests is negative. Block codes are defined in Figure 2. See text for explanation of Approach 2.

The multiple correlations of LAMP tests for the average accuracy scores across all blocks was .681 in Study 1 and .659 in Study 2. The comparable values obtained with ASVAB tests were .478 and .460, respectively. To put it another way, the LAMP tests accounted for more than twice the amount of criterion variance as was accounted for by the ASVAB tests. The *unique* contribution of LAMP tests to ASVAB tests in predicting the overall accuracy criteria was estimated to be at least 20% in both studies, using either of the described estimation approaches.

Decision on Need for Study 3

There are two factors which should be considered before accepting the findings in Studies 1 and 2. One deals with common-methods, and the other with concurrence. In the present studies, the LAMP tests and the gates course criterion tests were both presented by microcomputers, while the ASVAB tests were administered using paper-and-pencil procedures. The common methods may have given an advantage to the LAMP tests. This matter will be considered in the General Discussion section. The other factor concerns the fact that the LAMP tests and the course criterion tests were administered concurrently (in the same session), while the ASVAB tests had been administered some weeks or months previously in the operational testing stations. It is reasonable to expect that abilities measured at the time of course administration would be more valid predictors of course outcome than would be abilities measured at some prior point in time. This matter has been discussed and evaluated in at least two prior studies. Christal (1989) conducted a study based on several thousand subjects and found a small but significant concurrency effect. However, this study used ASVAB tests both as predictors and criteria. Divigi (1990) conducted a study to evaluate the incremental validity added by experimental tests to ASVAB in predicting job knowledge and hands-on-performance criteria in four occupations. In this study he used original ASVAB scores and scores from a version of the ASVAB administered concurrently with the experimental tests. He found the difference between incremental variance using concurrent and enlistment ASVABs to be "minor compared to variations across different criterion variables and occupational specialities."

In spite of the evidence that concurrency effects were not likely to be large, a decision was made to conduct a third study to specifically test for them in the context of validating ASVAB tests against criteria from the logic gates courses.

STUDY 3

With only three hours of testing time available, it was not possible to readminister the entire ASVAB along with a gates course. However, results from the factor analyses in both Study 1 and in Study 2 indicated that most of the predictive validity for the accuracy criteria came from measures of working memory. Since Arithmetic Reasoning, Mathematics Knowledge, and Mechanical Comprehension were the only ASVAB tests with significant loadings on this factor, analyses were conducted using Study 1 and Study 2 data to compare the multiple correlations of these three tests with those from the entire ASVAB in predicting the various accuracy criteria. The results from these analyses are presented in Table 21.

Table 21. Comparative Multiple Correlations of the Entire ASVAB and a Subset of ASVAB Tests for Accuracy Criteria in Study 1 and Study 2

	STUDY 1		STUDY 2	
	ASVAB	SUBSET*	ASVAB	SUBSET*
1-1	.381	.381	.460	.452
1-2	.359	.359	.424	.424
1-3	.315	.315	.376	.359
1-4	.295	.295	.363	.363
1-5	.310	.297	.273	.273
1-6	.255	.255	.238	.238
Av1	.255	.255		
1-7			.215	.215
1-8			.264	.243
Av1			.431	.431
2-1	.447	.429	.415	.415
2-2	.388	.378		
2-3	.391	.381		
2-4	.352	.352		
Av2	.433	.421		
Avg3			.428	.416
Avg4			.360	.360
AVG	.464	.460	.455	.455

Notes. * Subset of ASVAB tests is composed of Arithmetic Reasoning, Mathematics Knowledge, and Mechanical Comprehension. Block codes are defined in Figure 2.

The data in Table 21 confirm that essentially all of the criterion variance predicted by ASVAB could be captured by the three tests mentioned; therefore they were administered along with the Study 2 gates course to 312 airmen in the 11th day of basic military training. In order to gauge the magnitude of concurrency effects, multiple correlations for each of the course accuracy criteria were computed twice; once using scores on the three tests obtained from the operational testing files, and again, using scores on the three tests from the concurrent (retest) administration. The results of these analyses are presented in Table 22.

Table 22. Predictive and Concurrent Multiple Correlations of a Subset* of ASVAB tests for Study 2 Accuracy Criteria

BLK	PREDICTIVE	CONCURRENT
1-1	.456	.456
1-2	.478	.458
1-3	.455	.453
1-4	.362	.334
1-5	.338	.309
1-6	.290	.284
1-7	.251	.249
1-8	.206	.249
Av1	.453	.433
2-1	.523	.514
Av3	.498	.431
Av4	.495	.477
AVG	.534	.505

Notes. *The subset of ASVAB tests was composed of Arithmetic Reasoning, Mathematics Knowledge, and Mechanical Comprehension. Block codes are defined in Figure 2.

The data in Table 22 reveal little or no differences in the multiple correlations based on the original and concurrent test scores. Where differences did exist, they tended to be in the direction of higher validities for the original test scores. There are several possible explanations for this unexpected finding which will be addressed in the General Discussion section. However, the present results suggest that the concurrency effects were small, if they existed at all.

CORRECTIONS FOR RESTRICTIONS OF RANGE

Description of the Problem

All of the analyses reported thus far in this paper were based upon data collected from samples of airmen in Basic Military Training. Individuals in these samples were accepted into the U.S. Air Force from a general applicant population only after having met certain minimum aptitude requirement levels on ASVAB Aptitude Indexes (AI's). This selection process resulted in a restriction of range in the ASVAB test score distributions, which, in turn, yielded lower ASVAB test validities than would have been obtained in the full applicant population. There was also a restriction of range in the LAMP test-score distributions, to the extent that the LAMP tests correlated with the selection criteria. Finally, the differential restrictions of range due to selection resulted in overestimations of what the unique contribution of LAMP tests to ASVAB tests would be in the applicant population.

Approach

A decision was made to correct all of the intercorrelations and validities for range restrictions. However, a question arose. Which of three populations should serve as the basis for such corrections? The most stable would be the 18-23 year-old youth population for 1980, which was used for establishing the ASVAB norms. However, in my judgment, use of this population would not provide the most meaningful indication of the utility of the ASVAB in making selection decisions for an all-volunteer force, nor would it provide the most meaningful indication of the potential contribution of the LAMP tests to the ASVAB tests in making such decisions. The value of mental tests in maintaining an all-volunteer force should be gauged in terms of their power to identify the best-qualified individuals **from among those being considered for selection.** This being the case, the value of tests to the Department of Defense should be gauged in terms of their ability to identify the best qualified from among those applying for entry into the Uniformed Services; while the value of the tests to the U.S. Air Force should be gauged in terms of their ability to identify the best qualified individuals from among those applying for entry into the U.S. Air Force.

It is recognized that the nature of applicant populations changes over time; therefore, they would not be appropriate for establishing operational test norms. However, they can be used to estimate the value of the tests in selecting the best qualified from those being considered across a given time period. In the present study, a method suggested by Mifflin & Verna (1977) was applied to correct the test validities and intercorrelations to a random sample of 10,853 USAF individuals who applied for entry into the Air Force during 1980-1989. Results from analyses of these data are judged to be the best indication of the contribution of LAMP tests to ASVAB tests in making selection decisions in an all-volunteer force environment. Corrections would have been made to the DOD applicant population during this same time-period, but unfortunately, data were not available when this report was being prepared.

Data were available for approximately 10,000 subjects designed to be representative of the 25,408,193-case 1980 youth population described by Maier & Sims (1986). Corrections were made to this sample to get a rough indication of test utility in case of an all-out draft. However, in my judgment, use of this sample leads to an overcorrection. In the event of an all-out draft, a portion of those individuals in the upper-aptitude ranges would be siphoned off into officer training programs, and some in critical jobs or in college might be given deferments. Undoubtedly there would also be some individuals who are physically or mentally handicapped, or who have criminal records, who would be rejected prior to psychological testing. These factors lead one to predict that the range of aptitudes in the sample considered for draft into the enlisted ranks would be less than the range of aptitudes in the 1980 youth population. In spite of these concerns, corrections to this population were made.

Results

Tables 23 reports validities of the ASVAB and LAMP tests for the Study 1 gates course accuracy and latency criteria in the computing sample, as well as those corrected to the USAF applicant sample and the 1980 youth sample. Table 24 reports the same information based on Study 2 data. Table 25 reports data relating to the contribution of LAMP tests to ASVAB tests in predicting Study 1 gates course accuracy and latency criteria in the USAF applicant sample, while Table 26 reports these estimated contributions in the 1980 youth sample. Tables 27 and 28 are comparable to Tables 25 and 26, except that they are based upon Study 2 data.

Table 29 presents a summary of LAMP test contributions to ASVAB in accounting for Study 1 and Study 2 accuracy and latency criterion variance in the computing sample, in the USAF applicant sample, and in the 1980 youth sample. These contributions are impressive, even when the estimates are made using differences in adjusted R^2s which have been corrected to the 1980 youth sample.

Table 23. Validities of ASVAB and LAMP Tests for Study 1 Accuracy and Latency Criteria in the Computing Sample, the Air Force Applicant Sample and the 1980 Youth Sample

Test	ACCURACY			LATENCY		
	CS	AAS	YS	CS	AAS	YS
ASVAB						
GS	.13	.36	.52	-.01	-.13	-.22
AR	.40	.54	.65	-.06	-.16	-.25
WK	.20	.39	.54	-.03	-.14	-.24
PC	.16	.38	.51	-.03	-.14	-.24
NO	.08	.24	.44	-.13	-.21	-.29
CS	.09	.22	.40	-.10	-.17	-.25
AS	.10	.28	.39	.01	-.05	-.13
MK	.40	.51	.63	-.06	-.15	-.24
MC	.29	.43	.53	.03	-.06	-.15
EI	.26	.38	.53	.05	-.03	-.14
LAMP						
CRA	.27	.29	.32	.05	.03	-.00
NIA	.29	.32	.36	.07	.04	-.01
PIA	.27	.27	.28	.08	.07	.05
DSA	.32	.41	.50	-.07	-.12	-.19
NFA	.19	.23	.28	.04	.01	-.02
NRA	.47	.57	.67	-.07	-.15	-.24
MIA	.35	.44	.53	.14	.07	-.02
ABA	.44	.55	.65	.03	-.08	-.18
NAA	.48	.58	.68	-.11	-.19	-.27
CRL	.05	.01	-.07	.14	.16	.19
PIL	.11	.03	-.09	.32	.35	.38
NFL	.07	-.04	-.21	.31	.34	.40
MIL	.07	-.09	-.26	.21	.26	.32
ABL	.34	.25	.16	.35	.37	.39
NIL	.09	-.02	-.17	.36	.39	.43

Notes. Test abbreviations defined in Figure 1. CS = Computing Sample; AAS = Air Force Applicant Sample; YS = 1980 Youth Sample.

Table 24. Validities of ASVAB and LAMP Tests for Study 2 Accuracy and Latency Criteria in the Computing Sample, the Air Force Applicant Sample, and the 1980 Youth Sample

	ACCURACY			LATENCY		
Test	CS	AAS	YS	CS	AAS	YS
ASVAB						
GS	.21	.42	.57	-.19	-.31	-.40
AR	.34	.53	.65	-.18	-.29	-.39
WK	.17	.44	.59	-.06	-.22	-.33
PC	.12	.39	.52	-.07	-.21	-.30
NO	.15	.29	.49	-.12	-.19	-.31
CS	.11	.23	.42	-.11	-.18	-.29
AS	.07	.28	.42	-.02	-.14	-.23
MK	.38	.54	.65	-.17	-.26	-.36
MC	.29	.48	.57	-.08	-.20	-.29
EI	.18	.38	.55	-.05	-.16	-.29
LAMP						
GKA	.17	.40	.55	-.21	-.32	-.40
FRA	.36	.43	.48	-.15	-.20	-.25
MCA	.40	.51	.60	-.13	-.21	-.30
NIA	.23	.28	.36	-.02	-.05	-.12
PIA	.24	.25	.29	.04	.02	-.02
CRA	.28	.31	.34	.07	.04	-.01
ABA	.44	.58	.68	-.07	-.18	-.29
WAA	.39	.53	.62	-.14	-.24	-.33
NAA	.46	.56	.65	-.14	-.22	-.31
GKL	-.15	-.39	-.55	.27	.36	.43
NIL	-.11	-.22	-.37	.37	.41	.47
PIL	-.08	-.19	-.32	.38	.41	.47
ABL	.30	.23	.15	.29	.30	.32
CRL	-.17	-.25	-.36	.28	.32	.37

Notes. Test abbreviations defined in Figure 1. CS = Computing Sample; AAS = Air Force Applicant Sample; YS = 1980 Youth Sample.

Table 25. Contribution of LAMP Tests to ASVAB Tests in Accounting for Study 1 Criterion Variance in the USAF Applicant Sample

	R^2 Chg.	F	P value
Approach 1			
	ACCURACY		
ASVAB to LAMP	.035	3.319	.000
LAMP to ASVAB	.198	13.412	.000
Overall R = .743 R^2 = .552 Adj R^2 = .525			
	LATENCY		
ASVAB to LAMP	.005	.316	.977
LAMP to ASVAB	.211	8.129	.000
Overall R = .525 R^2 = .271 Adj R^2 = .228			

Approach 2

	ASVAB	LAMP	LAMP+ASVAB	L TO A
		ACCURACY		
R	.595	.719	.723	---
R^2	.354	.516	.552	.198
Adj. R^2	.339	.500	.525	.186
		LATENCY		
R	.245	.515	.521	---
R^2	.060	.265	.271	.211
Adj R^2	.039	.240	.228	.189

Notes. L to A reports the estimated contribution of LAMP tests to ASVAB tests.

Table 26. Contribution of LAMP Tests to ASVAB Tests in Accounting for Study 1 Criterion Variance in the 1980 Youth Sample

	R^2 Chg.	F	P value
Approach 1			
	ACCURACY		
ASVAB to LAMP	.029	3.411	.000
LAMP to ASVAB	.160	12.411	.000
Overall R=.798 R^2=.637 Adj R^2=.616			
	LATENCY		
ASVAB to LAMP	.005	.330	.973
LAMP to ASVAB	.201	8.129	.000
Overall R=.551 R^2=.304 Adj R^2=.263			

Approach 2

ACCURACY

	ASVAB	LAMP	LAMP+ASVAB	L TO A
R	.619	.780	.798	---
R^2	.477	.608	.637	.160
Adj. R^2	.465	.594	.616	.151
		LATENCY		
R	.320	.546	.551	---
R^2	.103	.298	.304	.201
Adj R^2	.082	.274	.263	.181

Notes. L to A reports the estimated contribution of LAMP tests to ASVAB tests.

Table 27. Contribution of LAMP Tests to ASVAB Tests in Accounting for Study 2 Criterion Variance in the Air Force Applicant Sample

	R^2 Chg.	F	P value
Approach 1			
	ACCURACY		
ASVAB to LAMP	.031	2.831	.002
LAMP to ASVAB	.176	11.395	.000

Overall R = .743 R^2 = .552 Adj R^2 = .526

	R^2 Chg.	F	P value
	LATENCY		
ASVAB to LAMP	.026	1.584	.109
LAMP to ASVAB	.192	8.260	.000

Overall R = .570 R^2 = .325 Adj R^2 = .285

Approach 2

ACCURACY

	ASVAB	LAMP	LAMP+ASVAB	L TO A
R	.613	.722	.743	---
R^2	.376	.521	.552	.176
Adj. R^2	.361	.505	.526	.165

LATENCY

	ASVAB	LAMP	LAMP+ASVAB	L TO A
R	.364	.547	.570	---
R^2	.133	.299	.325	.192
Adj R^2	.112	.275	.285	.173

Notes. L to A reports the estimated contribution of LAMP tests to ASVAB tests.

Table 28. Contribution of LAMP Tests to ASVAB Tests in Accounting for Study 2 Criterion Variance in the 1980 Youth Sample

	R^2 Chg.	F	P value
Approach 1			
ACCURACY			
ASVAB to LAMP	.027	3.054	.002
LAMP to ASVAB	.139	11.396	.000
Overall R=.805 R^2=.647 Adj R^2=.627			
LATENCY			
ASVAB to LAMP	.028	1.799	.059
LAMP to ASVAB	.178	8.255	.000
Overall R=.611 R^2=.374 Adj R^2=.337			

Approach 2

ACCURACY

	ASVAB	LAMP	LAMP+ASVAB	L TO A
R	.713	.788	.805	---
R^2	.508	.621	.647	.139
Adj. R^2	.497	.608	.627	.130

LATENCY

	ASVAB	LAMP	LAMP+ASVAB	L TO A
R	.442	.588	.611	---
R^2	.196	.346	.374	.178
Adj R^2	.176	.324	.337	.161

Notes. L to A reports the estimated contribution of LAMP tests to ASVAB tests.

Table 29. Summary of LAMP Test Contributions to ASVAB in Accounting for Study 1 and Study 2 Accuracy and Latency Criterion Variance

Approach 1

	ACCURACY		LATENCY	
	Study1	Study2	Study1	Study2
Computing Sample	23.6%	22.2%	22.0%	20.7%
A.F. Applicants	19.8%	17.6%	21.1%	19.2%
Youth Sample	16.0%	13.9%	20.1%	17.8%

Approach 2

	ACCURACY		LATENCY	
	Study1	Study2	Study1	Study2
Computing Sample	22.0%	20.6%	19.7%	18.5%
A.F. Applicants	18.6%	18.9%	16.5%	17.3%
Youth Sample	15.1%	18.1%	13.0%	16.1%

Notes. All values are in terms of the percent valid variance added by the LAMP tests to ASVAB tests in accounting for criterion variance.

While the difference in R^2s for the full and restricted model is the normal way of defining the unique contribution of one set of tests to another in accounting for criterion variance, Brogden (1946) argues that variation in the efficiency of a selective or predictive instrument (either a test or test composite) is a direct linear function of variation of its product-moment correlation (or multiple correlation) with the predicted variable. He demonstrates that the correlation (or multiple correlation) coefficient directly indicates the proportion of maximum saving that is actually obtained with use of the selection instrument, where the maximum saving is that obtained by selecting on the criterion. Data in Table 30 are provided to reflect the predictive efficiency of ASVAB and LAMP tests in accordance with this view. The values in the first two columns of numbers are the multiple correlation coefficients for the ASVAB and LAMP tests for the various gates course criteria obtained in the computing sample, in the USAF applicant sample, and in the 1980 youth sample. The values in the third column are the multiple correlations for the combined ASVAB and LAMP tests for these same criteria. The last column reports the differences in full model multiple correlation coefficients and the ASVAB multiple correlation coefficients, which, according to Brogden would indicate the increase in predictive efficiency contributed by the LAMP tests.

Table 30. Summary of Increases in Efficiency Contributed by LAMP tests to ASVAB Tests in the Prediction of Accuracy and Latency Criteria*

	Predictive Efficiency			Increased
	ASVAB	LAMP	A + L	Predictive Efficiency
ACCURACY, STUDY 1				
Computing Sample	.478	.656	.682	.204
A.F. Applicants	.595	.719	.743	.148
Youth Sample	.691	.780	.798	.098
ACCURACY, STUDY 2				
Computing Sample	.460	.635	.659	.199
A.F. Applicants	.613	.722	.743	.130
Youth Sample	.713	.788	.805	.092
LATENCY, STUDY 1				
Computing Sample	.161	.490	.496	.335
A.F. Applicants	.245	.515	.521	.276
Youth Sample	.320	.546	.551	.231
LATENCY, STUDY 2				
Computing Sample	.267	.507	.526	.259
A.F. Applicants	.364	.547	.570	.206
Youth Sample	.442	.588	.611	.169

Notes. Predictive efficiency is defined as the expected value of the gain effected by selecting with the selection composite to the gain that would be effected by selecting on the criterion itself. See the text for addition comments.

GENERAL DISCUSSION

The present paper is atypical of those usually published in the LAMP series in that it reports the results of applied rather than basic research. It contributes little if anything to our understanding of how individuals think, remember, solve problems, or process information in acquiring new knowledge or skills. However, basic research on cognition supported by the Air Force should have some probability of ultimate payoff in terms of improving selection, assignment, training, or some other aspect of the personnel system. Applied studies need to be conducted on occasion to see if progress is being made toward one or more of these goals. The levels of incremental validities found here at the very least attest to the fact that the LAMP approach is promising. However a number of factors should be considered in evaluating the final results, some of which are briefly treated in the following paragraphs.

Nature of the Learning Task

The learning task used in the present study was meaningful, but it was somewhat unusual in the sense that the airmen used as subjects had little or no incoming knowledge specific to the materials being taught. That is, it represented a novel learning situation. This is one of the reasons why ASVAB measures of technical and verbal knowledge, which have substantial validity for many technical school grades, had such low validities in the present study. It is anticipated that LAMP tests will add considerably less valid variance to the ASVAB tests in predicting technical school training grades than they did in predicting the criteria used in the present study. Most technical school grades reflect academic learning, and ASVAB tests historically have done well in predicting individual differences in academic learning. However, it is anticipated that the value of LAMP tests will be revealed against criteria involving the development of procedural skills, which tends to take place in the job environment.

Concurrency Effects

No concurrency effects were found in the present study. This was somewhat of a surprise, since one would expect abilities measured at the time of entry into a training course to have higher validities than abilities measured at some prior point in time. To the extent that this expectation was the case, the LAMP tests would have had an advantage over the ASVAB tests, which were administered some months earlier. Some possible explanations for the failure to find concurrency effects are given below:

1) It's simply a matter of ASVAB forms. Several forms of the ASVAB were administered in the operational testing stations, whereas a single form was used in the retesting session. Perhaps, for some unknown reason, the readministration form was inferior to the forms used in the operational

testing stations. This would be a simple explanation, but one which is difficult to accept by anyone who knows the care taken in ASVAB construction and norming.

2) The subjects were not motivated to do their best on the ASVAB retest, but regained motivation when faced with the novel computerized tests in the LAMP battery.

3) The ASVAB retest scores were poorer measures of working memory than were the original test scores. It is possible that there was differential forgetting of procedural and declarative knowledge between test and retest. If retention abilities do not predict the acquisition of a novel skill, the addition of retention factors to the concurrent ASVAB would lower its validity.

4) There is little or no concurrency effect since abilities do not change substantially during the interval between test and retest. This is the third study to suggest that currency effects are small. Perhaps they are in fact of little consequence.

Common Methods

There is a question of how much of the contribution of LAMP tests to ASVAB tests can be attributed to the use of common methods. It is true that the LAMP tests and the logic gates courses were both administered by microcomputer, while the ASVAB tests were administered by paper and pencil.

It would be difficult to accept that common methods played a significant role in determining the relationships of LAMP tests with accuracy criteria. If an individual correctly analyzed the input signals to a logic gate and knew the output to be either high or low, it should not have made much difference whether the answer was recorded by marking an answer sheet or pressing a computer key.

The same cannot be said with respect to predicting latency criteria. In the computing sample, none of the ASVAB test scores were significantly related to latency scores from the logic gates courses, while all of the latency scores from the LAMP tests showed validity for the course latency data. A basic question is "How much of an unfair advantage did the use of common methods give to the LAMP tests?".

To answer this question, one first should decompose the criterion variance into two parts: 1) that part which was relevant to the skill being taught, and 2) that part which was not relevant to the skill being taught. The relevant variance in the logic gates course latency data was associated with the time required for subjects to mentally process information to determine gate output signals. The non-relevant variance was associated with the time required to record answers using the computer keyboard. One might argue, then, that the variance associated with common methods may have given the LAMP tests some unfair advantage with respect to answer entry—but not with respect to measuring the time required for mental processing.[6]

Processing Accuracy

The LAMP measures of processing accuracy made a small but significant contribution to other LAMP measures in predicting accuracy criteria from the gates courses. These scores were extracted from simple processing speed tests having high accuracy levels. Within testing sessions, individuals who made errors on one of these tests tended to be the same individuals who made errors on the others. However, it is important to demonstrate that such tendencies are stable across time. If they are not, then the present analyses may have capitalized on some common-factor variance between the LAMP tests and the logic gate course criteria which will not hold up in a predictive sense.

Testing Time

Testing time is important when one is considering the utility of new tests for possible inclusion in future operational batteries. It is reasonable to ask whether the apparent advantage of LAMP tests in the present study was at the expense of excessive testing time. Unfortunately, it is not possible to give precise time requirements for the LAMP tests or for the logic gates courses, since the subjects proceeded at their own rate. However, the question can be answered in a gross fashion. About one hour was required for the slowest individuals to complete the course in Study 1, and about one-and-one-half hours was required for the slowest individuals to complete the course in Study 2. Since only three hours of testing time was available, a gross estimate is that the LAMP tests took about two hours for administration in Study 1 and one-and-one-half hours for administration in Study 2. In each instance, this is less time than was required for administration of the ASVAB.

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[6]One of the weaknesses of paper-and-pencil tests is that they do not provide a means for accurately measuring the speed of mental processing. In the case of solving logic gate problems, precision is needed to a tenth of a second in order to reliably discriminate between subjects. The wave of the future is computer-administered courses and computerized job tasks. The day may come, when even the time associated with keyboard entry is course and/or job related.

Of course, it should be recognized that neither the ASVAB nor the LAMP tests were designed with the logic gates course in mind. Both test sets were designed to measure knowledge and abilities relevant to learning in general. It is interesting to note that one of the LAMP tests with the highest validity for the accuracy criteria was Grammatical Reasoning, which took only five minutes for administration.

Other Considerations

Two factors stand out as explaining individual differences in the acquisition of declarative knowledge about gate rules and the development of procedural skill in solving logic gate problems. Information processing speed and working memory capacity were the best predictors of procedural skill development, and working memory capacity alone was by far the best predictor of rule learning.

The fact that ASVAB does not contain good measures of processing speed accounts for its inability to predict procedural skill development in the present study. The ASVAB does contain three tests which loaded on the Working Memory factor, and they accounted for essentially all of the ASVAB validity for gates course accuracy criteria. However, the ASVAB measures of working memory are heavily dependent on declarative and procedural knowledge gained in academic schooling, such as taking a square root or setting up equations to solve for an unknown. On the other hand, the LAMP tests of working memory yielded higher validities for the gates course accuracy criteria, and are less dependent on academic knowledge. For example, in the computing sample , the Arithmetic Reasoning and Mathematics Knowledge test validities for the average accuracy scores across all blocks in Study 2 were .34 and .38, respectively, while the Grammatical Reasoning, and Numerical Assignment tests in the LAMP battery correlated .44, and .46 with this same criterion. This advantage was maintained even in the data corrected to the USAF Applicant sample, where the values were .53 and .54 for the two ASVAB tests, compared with .58 and .56 for the two LAMP tests.

An important side benefit of using processing-based predictors is that they are not only more valid against certain criteria, but they also tend to be less related to Race and Sex. For example, in the Study 2 computing sample, the Arithmetic Reasoning test correlated .22 with Race (1/0= Non-Black/Black) while the Mechanical Comprehension test correlated .33 with Race and .29 with Sex (1/0=Male/Female). In contrast, the Grammatical Reasoning test (the highly valid 5-minute test), correlated only .11 with Race and -.01 with Sex. There appears to be some merit in considering some type of processing-based working memory test for future forms of the ASVAB.

CONCLUSIONS

Table 29 presents a summary of the major findings from Studies 1 and 2. In general, the LAMP tests added about 20% unique valid variance to the ASVAB in predicting both accuracy and latency block averages in the two logic gate courses. When the data were corrected for restrictions in range to the USAF applicant sample, the contributions of LAMP tests to ASVAB tests still ranged from 17% - 20%. The data in Table 30 show substantial contributions of the LAMP tests to the ASVAB tests in terms of increased predictive effeciency, where predictive efficiency is defined as the expected value of the gain effected by selecting with the selection composite to the gain that would be effected by selecting on the criterion itself.

Analyses indicated that the advantage of the LAMP tests over the ASVAB tests was not the result of a concurrency effect. Nor was it obtained at the expense of excessive testing time. Although the LAMP tests and criterion tests used common methods, arguments were presented contending that most of the covariance associated with common methods was meaningful to the task being learned and performed.

While the findings in the current study were for learning and skill development in a single subject-matter area, this subject-matter was selected because of its relevance to meaningful USAF functions. The results are viewed as being highly encouraging with respect to the potential contribution of the Learning Abilities Measurement Program (LAMP) to the USAF personnel system.

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APPENDIX A

DESCRIPTIONS OF ASVAB AND LAMP TESTS

The first ten tests listed are from the ASVAB and their descriptions are based on information in the Department of Defense Bulletin DOD 1340.12AA (1984).

ASVAB Tests Used in Study 1

General Science. This test contains 35 standard vocabulary items, such as "Which of the following foods contain the most iron? (a) eggs, (b) liver, (c) candy, (d) cucumber."

Arithmetic Reasoning. This test consists of 30 arithmetic word problems, such as the following: "Pat put in a total of 16 1/2 hours on a job during 5 days of the past week. How long is Pat's average workday? (a) 3 hours, (b) 3 hours, 15 minutes, (c) 3 hours, 18 minutes, (d) 3 hours, 25 minutes."

Word Knowledge. This test consists of 35 standard vocabulary items, such as "The wind is variable today. (a) mild, (b) steady, (c) shifting, or (d) chilling."

Paragraph Comprehension. This test consists of 15 paragraphs, each 1-to-3 sentences long, followed by a multiple-choice question of the paragraph's content. An example is the following:

From a building designer's standpoint, three things that make a home livable are the client, the building site, and the amount of money the client has to spend. According to the passage, to make a home livable

(a) it can be built on any piece of land;
(b) the design must fit the designer's income;
(c) the design must fit the owner's income and site;
(d) the prospective piece of land makes little difference.

Numerical Operations. This is a speeded test, consisting of 50 number-fact items (e.g., 2 x 6 =? (a) 4, (b) 8, (c) 3, (d) 12). Examinees are given 10 minutes to finish as many of the items as they can.

Coding Speed. This is a speeded test consisting of 84 items designed to measure how quickly an examinee can find a number in a table. An item consists of a word followed by five 4-digit number strings (e.g., (a) 6456, (b) 7150, (c) 8930, (d) 9645). The subject's task is to (a) look up the word's number code in a key consisting of 10 word-code pairs placed on top of the page, then (b) select the letter associated with that number code. Subjects are given 10 minutes to complete as many items as they can.

Auto and Shop Information. This tests consists of 25 questions about automobiles, shop practices, and the use of tools. An example question is: "A chisel is used for (a) prying, (b) cutting, (c) twisting, (d) grinding." Some of the questions include drawings of common tools or parts.

Mathematics Knowledge. This test consists of 25 arithmetic word problems (primarily algebra, but also area, square root, percentage, and simple geometry), such as the following: "If 3X = 5, then X = : (a) -2, (b) -5/3, (c) 3/5, (d) -3/5."

Mechanical Comprehension. This test consists of 25 questions relating to general mechanical and physical principles. The questions are normally accompanied by drawings. For example, a drawing may include three meshed gears with an arrow indicating the direction of rotation of one of the gears. The question might be "Which of the other gears is moving in the same direction as gear 1? (a) Gear 2, (b) Gear 3, (c) Both of the other gears, (d) Neither of the other gears."

Electrical Information. This test consists of 20 questions relating to knowledge of electrical, radio, and electronics information. Some of the questions contain drawings, while others do not. The following is an example question: "Which of the following has the least resistance?
(a) Iron, (b) Wood, (c) Silver, (d) Rubber."

LAMP Tests Included in Study 1

Choice Reaction Time. This test consists of 5 blocks of 20 items, for a total of 100. In each item, a block of 4 asterisks is presented on the right center or left center of the screen. If the asterisks appear on the right center, the subject is requested to press the 'L' key. If they are on the left center, the subject is requested to press the 'D' key. Latency in milliseconds and 'CORRECT' or 'WRONG' feedback is provided after each response. There is a 1-second intertrial time between items. Summary feedback is provided after each of the five blocks. Although individuals are requested to respond as quickly as possible without making mistakes, mistakes are in fact made by most subjects. The primary score extracted from the response data is 'median latency' in milliseconds. A 'percent correct' score is also computed and is used in the analyses.

Physical Identity. This test consists of 5 blocks of 20 items each, for a total of 100 items. In each item, two words are presented on the screen, one above the other. The words are either both in upper-case letters or both in lower-case letters. In 50 percent of the trials, the two words are physically identical. In the other 50 percent of the trials, the words are different, even though the case for the two words is the same. There is a warning asterisk prior to displaying each item. The subject is requested to press the 'L' key if the two words are physically identical, or the 'D' key if they are not. Response latency feedback is provided after each correct response, and the word 'WRONG' is presented, along with the sound of a buzzer, after each incorrect response. Summary feedback is provided at the end of each block. As in the case of the Choice Reaction Time test, both median latency and accuracy scores are obtained from the test results.

Name Identity. As in the case of the Choice Reaction Time and Physical Identity tests, this test contains 5 blocks of 20 items each, for a total of 100 items. Two words are presented in the middle of the screen, one above the other. One of the words is presented in upper-case letters, while the other is presented in lower-case letters. In 50 percent of the items, the two words are the same; in the other 50 percent, the two words are different (have a different name). The subject is requested to press the 'L' key if the two words have the same name, or the 'D', key if they have different names. The display format and the feedback provided is the same as in the Physical Identity test, above. Both latency and accuracy scores are derived from the test.

Meaning Identity. Meaning Identity is another information processing speed measure which contains 5 blocks of 20 items each. In each item, two words are displayed, one above the other, in the center of the screen immediately after a warning asterisk. Both words are presented in lower-case letters. The subject is instructed to press the 'L' key if the words have a similar meaning (are synonyms), or the 'D' key if they do not have similar a similar meaning. The words were selected to minimize the role of knowledge, since the goal is to measure speed of memory search, memory retrieval, and feature comparison. As in the case of the other processing speed measures, latency feedback is given on correct responses and 'WRONG' feedback is given on incorrect responses. Both median latency and percent correct scores were computed for all subjects.

Number Fact Retrieval. Subjects are given four sets of simple arithmetic problems: 50 addition (4 + 2), 50 multiplication (3 X 2), 25 subtraction (8 - 4), and 25 division (9 / 3). In each instance, the problem is displayed in the middle of the screen, with a proposed answer centered below it. The subject is instructed to press the 'L' key if the proposed answer is correct, or the 'D' key if the proposed answer is incorrect. Each problem is preceded with a warning star. Median latency and percent correct scores are obtained for each subject.

AB Grammatical Reasoning. AB Grammatical Reasoning is a computerized version of Baddeley's (1968) "3 minute test of grammatical reasoning." Subjects determine whether a sentence such as "A follows B" is consistent with an arrangement of the letters A and B (either "AB" or "BA"). The sentence and the letters appear on the screen simultaneously. Sentences are varied in relation (precedes vs. follows), voice (active vs passive), negation (present vs. passive), subject (A vs. B), and truth (true vs. false). There are $2^5 = 32 \times 2$ (replications) = 64 items, divided into four blocks. The computer provides latency and 'CORRECT' or 'WRONG' feedback after each item, and summary information at the end of each block. The computer displays items one-at-a-time, with no time limit. Both median latency and percent correct scores are computed for each subject.

123 Number Reduction. The 123 Number Reduction test is a modification of Thurstone and Thurstone's (1941) ABC Test. Subjects are asked to translate 2-, 3-, 4- ,5- and 6-digit numbers according to two rules. Rule 1 is to rewrite two successive same digits (e.g., 2 2) to that digit (i.e., 2). Rule 2 is to rewrite two successive different digits (e.g., 3 2) to the third digit (i.e., 1). The subject is instructed to evaluate pairs left-to-right and to enter the final digit resulting from the complete recoding sequence. This test was designed to measure working memory, since it involves processing in the presence of a memory load. The test is scored for percent correct only.

Digit Span. Digit Span is another test designed to measure working memory. The computer displays 5, 7, or 9 digits successively for 1 second each, left-to-right, 2 characters apart on the display screen. Immediately after the presentation, probe digits are presented one at-a-time from either the beginning or end of the list. The subject's task is to indicate (by pressing the 'L' or 'D' key) whether the probe matches the displayed digit. After the subject responds, a probe for the next-to-last digit is presented and subjects respond in the same fashion. On half of the items, probes are from the end of the list, and on the other half, from the beginning of the list. From 2 to 5 probes are displayed for each list. Subjects are given credit for each of the probes they correctly discriminate. Items are blocked by digit strings and are displayed in order (5-digit items first, followed by 7-digit and then two blocks of 9-digit items). There are eight 5-digit items (21 responses), ten 7-digit items (34 responses), 5 items in the first 9-digit block (21 responses), and 5 items in the second 9-digit block (23 responses), for a total of 4 blocks. The test provides summary percent correct feedback at the end of each block. It is scored only for percent correct.

ABC Numerical Assignment. This task, which in previous studies has been found to be a strong measure of working memory, consists of 21 items, each requiring three responses (63 probes, total), presented in a single block. Each item presents a sequence of screens in which each of the letters A, B, and C are assigned values or equations. A typical (but difficult) item is: (Screen 1) "A = B /2"; (Screen 2) "B = C - 4)"; (Screen 3) "C = 8"; (Screen 4) "B = ?"; (Screen 5) "A = ?"; (Screen 6) "C = ?". Letters were assigned either values (e.g., A = 5) or equations (e.g., A = B/2). In equation assignments, it was sometimes possible to solve for the equation with information already known. In other cases (such as in the example item), it is necessary to hold the equation in memory and wait for later screens to provide missing information that make it possible to solve the equation. The test allows unlimited per-screen study time, but subjects are not able to scroll backwards to review screens. The computer does not provide feedback.

ASVAB Tests in Study 2

Study 2 involved use of the same 10 ASVAB tests as described for Study 1, above.

LAMP Tests in Study 2

Choice Reaction Time. This is the same test as was used in Study 1, above.

Physical Identity. This is the same test as was used in Study 1, above.

Name Identity. This is the same test as was used in Study 1, above.

General Knowledge Test. Subjects are required to enter the first two letters of the single-word answers to 24 general knowledge questions such as "What is the name of the molten rock that flows down the sides of an active volcano?" (LAVA). The questions were selected from an earlier 100-item form using item-analysis procedures. The test is scored for both percent correct and latency.

Word Association Test. The subject is asked to associate 9 pairs of words in each of four study blocks. The word pairs in a block are presented one at-a-time at a rate of 4 seconds per pair. Each study block is followed by 9-alternative multiple-choice items in which the subject is presented with one member word of a pair and asked to identify the other member word with which it was associated. The distractors for each item are selected from among the 18 words used in the immediate block. The subject is provided with latency and accuracy feedback for each item, and summary accuracy and latency data at the end of each block.

Figure Recognition Test. In this test, figures are drawn by connecting lines between points in an invisible 9 by 9 dot matrix. Of the over one-million potential figures, 160 were selected which were judged to be at least moderately encodable. In each of four blocks, 20 of the figures were displayed in a 5 by 4 matrix for a 75-second study time. The subjects are asked to study each figure so that they will recognize it if they see it again. Subjects are encouraged to give meaning to figures by associating them with known objects or scenes. At the end of the 75-second study period, 40 figures are presented one-at-a-time. If a figure is judged to be one of the 20-figure study set, the subject is asked to press the 'L' key. Otherwise, the subject is asked to press the 'D' key. Accuracy and latency feedback is provided after each response, and summary feedback is provided at the end of each block. This test is scored for percent correct only.

Mental Character Generation. In this test, the subjects are asked to commit to memory the numbers from 1 to 9 in the relative locations shown below:

1	4	7
2	5	8
3	6	9

For a particular item, subjects are asked to mentally connect numbers with lines in accordance with instructions displayed on successive screens. While processing a given screen, the subjects must retain a mental image of the figure drawn by previous instructions, and add to this figure the line called for by the present instruction. If the instructions are properly executed, at the end of the last instruction in a set, the mental image of a letter or number will have been generated. The subjects are asked to record this letter or number by pressing the corresponding key. For example, here are the instructions for one of the items:

screen 1: connect 3 to 1
screen 2: connect 7 to 6
screen 3: connect 1 to 6
screen 4: ?

The correct answer to the above item is the letter 'V'. There are only 13 items in this test. Two of them involve connecting 2 lines, two, 3 lines; four, 4 lines; three, 5 lines; and two, 6 lines. The subjects are permitted to move at their own pace, and feedback is provided on accuracy. This test was designed to be a measure of working memory involving spatial materials. It requires storing a mental image while processing additional visual information.

Tests used in Study 3

Study 3 did not involve administration of any tests from the LAMP program. It involved only the administration of three alternate forms of tests from the ASVAB (Arithmetic Reasoning, Mathematics Knowledge, and Mechanical Comprehension). These tests were selected as the three ASVAB tests that were most predictive of learning in the Logic Gates Course. The purpose of Study 3 was to evaluate the possible influence of concurrency on computed validity coefficients.

APPENDIX B

FACTOR ANALYSIS OF STUDY 1 AND STUDY 2 TEST SCORES

Study 1 Factor Matrix

Table B1. Results from Factor Analysis of Study 1 Predictor Tests

TEST	PROCSPD	WKMEM	PROCACC	VERBAL	TECHKNOW	NUM/PS
NIL	.89	-.04	.05	-.01	.00	-.17
PIL	.81	-.07	.17	.04	.04	-.12
MIL	.69	-.10	-.03	-.15	-.02	-.08
CRL	.50	-.05	.08	.01	-.03	-.02
NAA	-.09	.74	.21	.11	.08	.16
DSA	-.20	.58	.19	-.09	.07	.03
MK	.03	.58	-.02	.30	.14	.36
AR	-.02	.55	.07	.20	.27	.29
NRA	-.15	.54	.30	.21	.08	.07
ABA	.02	.47	.30	.34	.04	-.08
PIA	.15	.01	.77	-.03	-.00	.07
NIA	-.02	.05	.73	.04	.03	.10
MIA	.06	.20	.68	.15	-.03	-.04
CRA	.07	.13	.43	-.04	.11	.05
NFA	,03	.22	.33	-.03	.00	-.01
ABL	.23	.21	.32	-.13	.03	-.21
WK	-.06	.24	-.04	.76	.15	-.13
GS	.04	.11	-.13	.63	.37	-.11
PC	-.07	.04	.08	.61	.15	.11
EI	.05	.14	.04	.31	.71	-.07
AS	.01	.02	.09	.09	.69	-.17
MC	-.02	.32	.03	.25	.60	-.08
NO	-.09	.17	.07	-.06	-.18	.67
NFL	.50	-.08	.15	.06	.10	-.56
CS	-.20	.13	.14	-.03	-.11	.50

Notes. See Figure 1 for test titles. Loadings are from Varimax rotations of Principal Axis Factors.

Study 1 Factor Descriptions

FACTOR I-- PROCESSING SPEED

This factor was defined solely by latency scores from LAMP tests designed to measure processing speed, including the Name Identity, Physical Identity, Meaning Identity, Choice Reaction, and Number Fact Recall tests. No test from the ASVAB had significant loadings on this factor.

FACTOR II-- WORKING MEMORY

All of the LAMP tests selected to be measures of working memory had significant loadings on this factor. The test with the highest loading was the Number Assignment test (sometimes called the ABC Recall Test), which has been the primary definer of working memory in several previous studies (Christal. 1988; Kyllonen & Christal, 1989, 1990). The three ASVAB tests with significant loadings on this factor were Mathematics Knowledge, Arithmetic Reasoning, and Mechanical Comprehension, all of which have had significant loadings on the working memory factor in previous analyses (Christal, 1988). In the Study 1 factor analysis, it so happened than many of the tests defining the working memory factor were based on processing numerical content. However, the fundamental nature of the factor is believed to be the requirement for information processing in the presence of a memory load, and unpublished LAMP studies suggest that this factor may not be heavily influenced by the type of content processed. All of the tests in Study 1 required the subjects to store intermediate results while completing the processing demanded for problem solution.

FACTOR III -- PROCESSING ACCURACY

This factor was defined by accuracy scores from simple LAMP processing speed measures. Most subjects made near-perfect scores on such tests. For example the tests with the top four loadings on this factor were Physical Identity, Name Identity, Meaning Identity, and Choice Reaction, for which the mean percent accuracy scores were 95.5, 95.4, 93.2, and 98.5, respectively. Although few errors were made on these simple processing tasks, the subjects who made the most errors on one of these tests tended to be those who also made the most errors on the others.

FACTOR IV -- VERBAL

This is the verbal factor which is routinely identified in analyses of ASVAB tests. In the present study it was defined by the Word Knowledge, Paragraph Comprehension, and General Science tests. None of the LAMP tests were designed to measure verbal knowledge, and none had large loadings on this factor.

FACTOR V -- TECHNICAL KNOWLEDGE

This is the technical knowledge factor which is routinely found in factor analyses of the ASVAB tests. It was defined by Electrical Information, Auto and Shop Information, Mechanical Comprehension, and General Science. The only LAMP test that had a significant loading on this factor was Grammatical Reasoning, which had a loading of only .34.

FACTOR VI -- NUMERICAL FACILITY/PERCEPTUAL SPEED

Factor analyses of tests from the ASVAB normally yield a doublet factor defined by Numerical Operations and Coding Speed. This is often labeled as being a perceptual speed factor. In the present analysis, the LAMP Number Fact Recall test joined the two ASVAB tests in defining the factor, and had the second highest loading on it. Since two of the three tests defining the factor involve simple numerical computations under speeded conditions, it was labeled in this study as being a "Numerical Facility/Perceptual Speed" factor.

Table B2. Results from Factor Analysis of Study 2 Predictor Tests

TEST	VERBAL	WKMEM	PROCSPD	PROCACC	TECHKNOW	NUM/PS
WK	.73	.09	-.04	.01	.09	-.07
GKA	.68	.21	-.06	-.02	.20	-.11
GS	.64	.21	-.06	-.01	.38	-.00
GKL	-.59	-.10	.21	.11	-.08	-.35
PC	.53	.05	-.06	.04	.05	.13
NAA	.07	.71	-.04	.22	.00	.17
MK	.19	.59	-.01	-.03	.02	.43
AR	.11	.54	.06	-.04	.21	.47
MCA	.14	.51	-.10	.12	.13	.02
FRA	.06	.50	-.24	.23	.09	-.18
WAA	.30	.46	-.23	.20	.06	-.11
ABA	.36	.43	-.00	.25	.08	.12
PIL	-.06	-.07	.84	.18	-.03	-.19
NIL	-.16	-.03	.84	.13	.09	-.22
CRL	-.08	-.17	.51	.17	-.01	-.05
PIA	-.00	.07	.12	.76	-.01	.14
NIA	.07	.10	.08	.66	-.00	.08
CRA	-.03	.18	.11	.46	.12	-.00
ABL	-.05	.26	.20	.42	-.08	-.19
AS	.11	-.05	.06	-.01	.78	-.12
MC	.19	.32	-.02	-.02	.63	-.03
EI	.29	.10	-.01	.13	.63	-.06
NO	.02	.07	-.18	.07	-.10	.63
CS	.00	.04	-.19	.08	-.15	.60

Notes. See Figure 1 for test titles.

Factor Descriptions

The factor descriptions for the Study 2 analysis are identical to those for Study 1, with the following exceptions: 1) the Working Memory factor is now defined by spatial and verbal tests, in addition to quantitative tests; 2) the Processing Speed factor is a little weaker because the Meaning Identity test was no longer in the battery; and 3) the Numerical Facility/Perceptual Speed factor contains less numerical variance because the Number-Fact Retrieval test had been dropped.

APPENDIX C

VALIDITIES OF ASVAB AND LAMP TESTS FOR STUDY 1 AND STUDY 2 ACCURACY AND LATENCY CRITERIA

Table C1. Validities of ASVAB and LAMP tests for Study 1 Accuracy Criteria

	BLOCK AVERAGES		
TEST	Av1	Av2	AVG
ASVAB			
GS	.06	.15	.13
AR	.38	.33	.40
WK	.13	.22	.20
PC	.09	.20	.16
NO	.12	.03	.08
CS	.12	.06	.09
AS	.05	.12	.10
MK	.34	.36	.40
MC	.20	.31	.29
EI	.16	.28	.26
LAMP			
CRA	.25	.24	.27
NIA	.26	.25	.29
PIA	.28	.21	.27
DSA	.31	.28	.32
NFA	.18	.16	.19
NRA	.41	.43	.47
MIA	.33	.31	.35
ABA	.40	.40	.44
NAA	.47	.39	.48
CRL	.06	.02	.05
PIL	.11	.08	.11
NFL	.03	.09	.07
MIL	.10	.02	.07
ABL	.28	.34	.34
NIL	.09	.06	.09

Notes. Block codes are defined in Figure 2. Test abbreviations are defined in Figure 1.

Table C2. Validities of ASVAB and LAMP tests for Study 1 Latency Criteria

TEST	BLOCK AVERAGES Av1	Av2	AVG
ASVAB			
GS	-.04	.04	-.01
AR	-.13	.02	-.06
WK	-.06	.01	-.03
PC	-.04	-.01	-.03
NO	-.10	-.12	-.13
CS	-.10	-.08	-.10
AS	-.03	.05	.01
MK	-.10	.00	-.06
MC	-.01	.01	.03
EI	.00	.07	.05
LAMP			
CRA	.05	-.01	.05
NIA	.03	.06	.07
PIA	.04	.10	.08
DSA	-.12	-.04	-.07
NFA	.00	.07	.04
NRA	-.14	-.01	-.07
MIA	.05	.17	.14
ABA	-.05	.12	.03
NAA	-.17	-.04	-.11
CRL	.16	.19	.14
PIL	.33	.29	.32
NFL	.28	.34	.31
MIL	.19	.25	.21
ABL	.23	.40	.35
NIL	.35	.34	.36

Notes. Block codes are defined in Figure 2. Test abbreviations are defined in Figure 1.

Table C3. Validities of ASVAB and LAMP Tests for Study 2 Accuracy Criteria

TEST	Av1	2-1	Av3	Av4	AVG
			BLOCK AVERAGES		
ASVAB					
GS	.13	.21	.20	.22	.21
AR	.33	.35	.33	.26	.34
WK	.11	.15	.19	.16	.17
PC	.07	.11	.11	.13	.12
NO	.14	.14	.14	.12	.15
CS	.13	.10	.07	.08	.11
AS	-.03	.13	.13	.08	.07
MK	.40	.33	.32	.30	.38
MC	.21	.27	.31	.26	.29
EI	.08	.20	.20	.19	.18
LAMP					
GKA	.14	.15	.14	.16	.17
FRA	.34	.26	.28	.34	.36
MCA	.37	.29	.34	.39	.40
NIA	.20	.25	.22	.20	.23
PIA	.25	.18	.20	.19	.24
CRA	.30	.17	.20	.26	.28
ABA	.39	.36	.38	.41	.44
WAA	.35	.31	.33	.36	.39
NAA	.44	.36	.36	.43	.46
WKL	-.10	-.16	-.16	-.15	-.15
NIL	-.11	-.07	-.07	-.11	-.11
PIL	-.09	-.04	-.05	-.08	-.08
ABL	.24	.21	.24	.33	.30
CRL	-.12	-.17	-.17	-.18	-.17

Notes. Block codes defined in Figure 2. Test abbreviations defined in Figure 1. The values under 2-1 are for a single block of simple gates with negations.

Table C4. Validities of ASVAB and LAMP Tests for Study 2 Latency Criteria

	BLOCK AVERAGES				
TEST	Av1	2-1	Av3	Av4	AVG
ASVAB					
GS	-.19	-.15	-.18	-.07	-.19
AR	-.23	-.17	-.14	-.09	-.18
WK	-.09	-.01	-.04	-.02	-.06
PC	-.06	-.06	-.09	-.01	-.07
NO	-.14	-.09	-.10	-.13	-.12
CS	-.08	-.06	-.13	-.14	-.11
AS	-.02	-.09	-.01	-.00	-.02
MK	-.22	-.14	-.14	-.06	-.17
MC	-.14	-.11	-.05	.01	-.08
EI	-.09	-.04	-.05	.05	-.05
LAMP					
GKA	-.22	-.17	-.19	-.10	-.21
FRA	-.22	-.13	-.13	.01	-.15
MCA	-.23	-.14	-.11	.04	-.13
NIA	-.09	.02	.04	.01	-.02
PIA	-.02	.05	.08	.03	.04
CRA	-.03	.02	.06	.18	.07
ABA	-.17	-.07	-.03	.07	-.07
WAA	-.27	-.09	-.11	.07	-.14
NAA	-.27	-.16	-.13	.06	-.14
GKL	.26	.24	.25	.18	.27
NIL	.38	.25	.35	.22	.37
PIL	.37	.28	.36	.25	.38
ABL	.10	.22	.26	.41	.29
CRL	.33	.26	.23	.15	.28

Notes. Block codes defined in Figure 2. Test abbreviations defined in Figure 1. The values under 2-1 are for a single block of simple gates with negations.

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