Broad Technical Skills 5

The world of work is changing rapidly, and in ways that are difficult to anticipate. In response to this change and in an effort to make vocational education a method of equipping young people for more than one occupational future, policymakers and educators have begun to seek skill training and preparation that applies to many jobs. The language of the 1990 amendments to the Carl D. Perkins Vocational Education Act refers to ' 'broad technical skills, " The Office of Technology Assessment (OTA) was asked to determine how much testing and assessment was aimed at measuring the mastery of these skills. This concept is a new one, however, and no agreement exists on what skills are truly lifetime occupational skills, or on how those skills are best acquired.

Very few states are moving toward organizing their vocational programs around broad technical skills. One of the principal reasons for this is the lack of research and proven experience showing what broad technical skills are, how they can be taught and assessed, and what the advantages and disadvantages of such a change would be.

The implications of organizing vocational programs around broad technical skills are potentially far reaching. Large segments of the training enterprise in this country are oriented to providing people with just the skills needed for particular jobs instead of careers. By organizing more of training around the development of broad technical skills, a greater proportion of the total training effort might be directed to the preparation of people for careers and learning on the job rather than for specific entry-level positions. This lengthening of the ' 'skill horizon' of vocational education and other training efforts would require

placing greater emphasis on developing capabilities for thinking, responding to the unexpected, and taking initiative, in addition to acquiring the skills needed for performing specific occupational tasks.

Broadening the technical and occupational skills around which vocational education is organized could also help to facilitate the integration of academic and vocational education. By shifting the content of vocational preparation toward the development of capabilities that require more thinking and knowledge application, opportunities should expand for connecting occupational and academic content.

Whether the potential advantages from broadening the technical skills concept can be realized is an open question. Certain major fields of vocational education have historically been much more broadly oriented than others. Agriculture is a clear example, while the trades have been more specialized. The recent pressures on all fields, including agriculture, have been to become more competency based and job oriented.

The main purpose of this chapter is to suggest some alternative ways of beginning to define broad technical skills. Much more thought needs to be given to this basic concept than has been given to it so far.

Broad technical skills are different from generic workplace skills in certain key respects. The main difference is that generic workplace skills have been defined as essentially the same across industries. Whether people who have these generic workplace skills in one industry or occupational area in fact demonstrate them with equal proficiency in other occupational or industry areas has not been shown.

The concept of broad technical skills reflects much more directly the content of technology, information, and methods of organization within an industry or group of industries. It is possible that these industry groups could be as broad as health care, financial services, manufacturing, hospitality, and agribusiness; or it may be necessary to limit them to occupational areas within industry groups. Both broad technical skills and generic workplace skills may be important for productivity in the workplace and career development. Broad technical skills will be defined in this report to include not only the specific technical content of job performance but background knowledge of the technological, social, and economic development of the industry.

Five different approaches to defining broad technical skills are described in this chapter. The approaches are: vocational abilities and aptitudes, occupational maps, core occupational skills, design and technology, and cognitive problem solving. They are founded on fundamentally different assumptions about the nature of skills, relationships between skills and the contexts in which they are used, and relationships between general and specific skills. The approaches differ greatly in the extent to which they are supported by research; some reflect extensive analysis and others exist primarily as practices or even ideas for improvements in practice, These approaches do not exhaust the range of possibilities.

VOCATIONAL APTITUDES

One approach to defining broad technical skills is to think of them as vocational aptitudes. The thesis of vocational aptitude testing is that people perform best in the jobs or occupational fields for which they have the most "abilities' and that these abilities can be identified through tests. The instruments developed for assessing vocational aptitudes employ the techniques of testing for achievement and multiple abilities developed from research in psychology on mental testing and intelligence.[1] Aptitude tests differ from tests of achievement mainly in the uses that are made of the results rather than the abilities measured

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[1] Lee J. Cronbach, *Essentials of Psychological Testing* (New York, NY: Harper and Row, 1990), ch. 10.

and the nature or content of the tests employed.[2] Aptitude tests are constructed to measure the likelihood that a person will perform well in the future in different kinds of jobs or occupational fields, while achievement tests are primarily intended to measure what a person has learned in response to education, such as a training program for computer technicians or mathematics up to a certain grade in high schools

Most aptitude tests consist of several individual tests for different areas of knowledge or ability. The tests are selected because of their contribution to the accuracy with which performance in a subsequent job or occupation can be predicted. These component tests of the overall test ''battery' typically include measures of what can be considered pure cognitive ability, such as memory span, spatial reasoning ability, or perceptual speed; academically related achievement, such as vocabulary, reading comprehension, or arithmetic problem solving; perceptual-motor skills, such as manual dexterity or eye-hand coordination; and other areas of knowledge or skill more specific to the occupations of interest.[4] These four domains of ability are different from a person's vocational interests and personality characteristics, which can also be measured through another kind of test called an ''interest inventory, such as mechanical comprehension or computer knowledge. Both vocational aptitude tests and interest inventories have been shown to be significantly related to job performance.[5]

Tests of vocational aptitude are developed primarily for purposes of career counseling or screening people for selection into jobs or occupational areas. Because of their origins in mental testing, the format of most aptitude tests is written, except for measures of perceptual-motor skills. Because of the written format, aptitude tests can be group administered and are therefore relatively inexpensive. This is essential given the primary use of this kind of test, which is screening large numbers of job applicants.

One view is that the knowledge and abilities measured through vocational aptitude testing are prerequisites for success in different kinds of jobs. Another interpretation is that measurement of knowledge and abilities provides an indication of the individual's capability for learning new tasks that are similar to those that will be performed on the job. This latter interpretation opens a door to making connections among the different approaches to broad technical skills.

Vocational aptitudes differ from job competencies in that they are presumed to underlie people's performance of tasks on the job. Job tasks describe specific behaviors that people exhibit in response to certain work goals or

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[2] "Achievement and aptitude tests are not fundamentally different. . . . Tests at one end of the aptitude-achievement continuum can be distinguished from tests at the other end primarily in terms of purpose. For example, a test for mechanical aptitude [could] be included m a battery of tests for selecting among applicants for pilot training since knowledge of mechanical principles has been found to be related to success in flying. A similar test [could] be given at the end of a course in mechanics as an achievement test intended to measure what was learned in the course.'' National Academy of Sciences Committee on Ability, *Ability Testing: Uses, Consequences, and Controversies: Part I: Report of the Committee* (Washington, DC: National Academy Press, 1982), p. 27.

[3] Anne Anastasi, *Psychological Testing*, 6th ed. (New York, NY: Macmillan Publishing Co., 1988), p. 412.

[4] Psychologists" frequently distinguish between "fluid" intelligence, such as spatial ability, visualization ability, short-term memory, and so forth, and ''crystal] ized' intelligence, which is the product of experience, such as arithmetic reasoning and word knowledge. The theory is that people use their fluid abilities to obtain crystallized abilities. See, for example, Richard E. Snow, "Aptitude Theory: Yesterday, Today, and Tomorrow, *Educational Psychologist, vol. 27, No. 1, 1992,* pp. 5-32. A wide range of predictor variables for vocational aptitude testing is discussed in Norman G. Peterson et al., ''project A: Specification of the Predictor Domain and Development of New Selection Class ification Tests, " *Personnel Psychology*, vol. *43, No. 2,* summer 1990, pp. *247-276.*

[5] Generally, the findings are [hat cognitive and perceptual-psychomotor ability tests provide the best prediction of job-specific and general task proficiency, while measures of temperament and personality are the best predictors of giving extra effort, supporting peers, and exhibiting personal discipline. Scores derived from interest inventories correlate more highly with task proficiency than with demonstrating effort and peer support. Jeffrey J. McHenry et al., ''project A Validity Results: The Relationship Between Predictor and Criterion Domains,'' *Personnel Psychology*, vol. 43, No. *2,* summer 1990, pp. 33 S-354.

demands of the job environment, and job competencies are tasks that people have demonstrated that they are able to perform repeatedly. The concept of vocational aptitudes is that the performance of these specific tasks requires a certain combination of abilities, or traits, as they are sometimes called, and that different tasks require different combinations of these abilities or traits. Their mental basis is what lends these traits or abilities their presumed generality of application across many different kinds of specific tasks. Job competencies, on the other hand, are not generally presumed to be transferable across jobs or work situations in the ways that they are usually defined. There is no model of transfer built into the job competency model. Aptitudes are thus at one extreme essentially fixed (though learnable) qualities of the mind, while job competencies (or job tasks) describe highly specific, observable job behaviors that vary greatly from job to job. A "giant leap" of faith is required to translate between the two.[6]

Two approaches to filling this gap are described later in this chapter. One is occupational mapping, which involves broadening the definition of job tasks to cover whole clusters of occupations and revising the nature of the task descriptions to include thinking as well as behavior. The other approach is the cognitive skills model, which provides a detailed description of the thinking processes involved in acquiring the knowledge required in a job domain, and becoming expert at performing a range of tasks in the domain and responding to a variety of new task demands.

Vocational aptitudes are important to consider in defining broad technical skills because of the way the tests are developed. A number of different areas of knowledge and abilities are hypothesized to be significant predictors of performance in a range of jobs or occupational areas. Each of the abilities is then described in terms of a "construct' or hypothesized relationship between processes of thinking and observable aspects of performance. Subtests for each of these constructs are then developed and assembled into a larger test for administration to a sample of individuals to obtain information about how their scores on the subtests are related to measures of their performance. Methods of statistical inference are employed to determine which of the subtests provide the greatest capability for distinguishing between high and low performers across the range of jobs or occupations selected. Constructs found through this process to be highly correlated with performance that is ''technical in nature can then be considered candidates for broad technical skills.

One important example of a vocational aptitude test is the Armed Services Vocational Aptitude Battery (ASVAB). The ASVAB is used by the military for selecting personnel into the armed forces and assigning them to jobs and initial training. It consists of 10 subtests, as shown in table 5-1.

The military also provides the ASVAB free of charge to high schools as the main part of a nationwide student career counseling program. Over a million high school students take the ASVAB every year (out of, for example, the approximately 2.4 million seniors in 1992[7]). The ASVAB is administered in the schools by personnel from the Military Entrance Processing Command and scored by them. Each school receives in return a report on students' performance and each student a complete profile of his or her scores, a guide to military careers, and carefully

6 Alexandra K. Wigdor and Bert F. Green, Jr. (eds.) *Performance Assessment in the Workplace, Vol. I* (Washington, DC: National Academy Press, 1991), p. 85.

7 See footnote 14 in ch. 4 of this report.

Table 5-1-Subtest Content Areas of the Armed **Services Vocational Aptitude Battery**

Subtest content area	Description of the subtest
General science (GS)	Knowledge of the physical and biological sciences
Arithmetic reasoning (AR)	Word problems emphasizing mathematical reasoning rather than mathematical knowledge
Word knowledge (WK)	Understanding the meaning of words, i.e., vocabulary
Paragraph comprehension (PC)	Presentation of short paragraphs followed by multiple-choice items
Numerical operations (NO)	Speeded test of four arithmetic operations
Coding speed (CS)	Speeded tests of matching words and four-digit numbers
Auto and shop information (AS)	Knowledge of auto mechanics, shop practices, and tool functions in verbal and pictorial terms
Mathematics knowledge (MK)	Knowledge of algebra, geometry, and fractions
Mechanical comprehension (MC)	Understanding of mechanical principles, such as gears, levers, and pulleys
Electronics information (El)	Knowledge of electronics and radio principles in verbal and pictorial terms

SOURCE: John R Welsh and Susan K. Kucinkas, *Armed Services Vocational Battery: Integrative Review of Validity Studies,* AFHRL-TR-90-22 (Brooks Air Force Base, TX: Human Resources Laboratory, July 1990), table 2.

prepared instructions explaining how they can use the information to decide which military occupations they are best qualified to pursue.[8]

Scores on the ASVAB have been shown to predict job performance reasonably well using a number of different criteria: grades in training school; scores on job-specific, hands-on performance assessments; scores on job knowledge tests;[9] supervisor ratings; field proficiency ratings; and many other variables.[10] The multiple correlation between ASVAB scores and normalized scores on the job performance assessments is typically in the neighborhood of 0.6, which the National Academy of Sciences has concluded is a "useful amount.[11] This correlation of 0.6, with some variation higher and lower, has held across many different kinds of military jobs[12] and to some extent equivalent civil i an jobs.[13] The total amount of variance in the criterion variable explained by this correlation of 0.6, whether it is grades in training school or hands-on job performance, is

[8] U.S. Department of Defense, Defense Manpower Data Center, *Counselors Manual for* (he *Armed Services Vocational Aptitude Battery,* DOD 1304. 12-L-ASTP-CM (North Chicago, IL: U.S. Military Entrance Processing Command, July 1992).

[9] Job Anew ledge tests are essentially the same type of test as the job competency test discussed in ch. 3.

[10] Charlotte Campbell et al., "Devel(qment of Multiple Job Performance Measures in a Representative Sample of Jobs," *Personnel Psychology,* vol. 43, No. 2, summer 1990, pp. *277-300.* See also Paul W. May berry and Neil B. Carey, *Relationship Between ASVAB and Mechanical Maintenance Job Performance,* CRM 92-1929 (Alexandria, VA: Center for Naval Analysis, March 1993). An extensive set of hands-on job performance measures was developed for the joint service Job Performance Measurement project overseen by the National Academy of Science\, which are utilized in these and many of the other studies reported in this chapter.

[11] Wigdor and Green (eds.), op. cit., footnote 6, p. 163.

[12] Ibid. p. 151 Milton Maier, *Military Aptitude Testing: The Past Fifty Years,* DMDC Technical Report 93-007 (Monterey, CA: Defense Manpower Data Center, June 1993), p. 6; and Paul W. May berry, *Validation of ASVAB Against Infantry Job Performance,* CRM 90-182 (Alexandria, VA Center for Naval Analysis, December *1990). The* predictive validity ranges from 0.2 or higher to over 0.70, but in most jobs is about ().6. Ibid., p. 1263, *These* correlations are all corrected for "restriction of range," according to the procedures recommended in Stephan Dunbar and Robert Linn, "Range Restriction Adjustments in the Prediction of Military Job Performance," *Performance Assessment in the Workplace, Vol. //,* Alexandra K. Wigdor and Bert F. Green, Jr. (eds.) (Washington, DC: National Academy Press, 1991), pp. 127-157. The correction for restriction of range involves adjusting the computed correlation between ASVAB scores and the criterion variable for the fact that performance scores are available (rely for Individuals who have been selected for the military. Without correcting for the restriction of range, the predictive validity of the ASVAB is in the neighborhood of 0.4. Corrections are also sometimes made for unreliability of the criterion measure in some analyses of predictive validity.

[13] R.L.~{,)lmgren and M.R. Dalldorf, A *Validation of the ASVAB Against Supervisors' Ratings in Civilian Occupations* (Palo Alto, *CA* American Institutes for Research. 1993),

generally about 25 percent.[14] The predictive validities of the ASVAB are somewhat higher for grades in training school than for hands-on performance assessments (0.1 to 0.2 higher), and somewhat lower but much more variable for field proficiency ratings and supervisor ratings. 's

Research in the Marines shows that the predictive value of the ASVAB continues after the first term of enlistment for both infantry and leadership personnel. The main finding is that over 3 years of experience are required for personnel with low tested aptitude on the ASVAB to reach the same level of proficiency on the job performance assessments as high aptitude personnel demonstrate in their first year.[16]

The critical question for the purposes of this chapter is the contribution of the three technically oriented aptitudes to job performance in comparison to the academically and cognitively oriented aptitudes, and the extent to which these technical aptitudes are more critical for performance in some occupations than others.

Factor analysis shows that scores on the 10 different tests of the ASVAB can be reduced to four intercorrelated factors: verbal aptitude (general science, word knowledge, and paragraph comprehension), mathematical aptitude (arithmetic reasoning and mathematics knowledge), cognitive speed (numerical operations and coding speed), and technical aptitude (auto and shop information, mechanical comprehension, and electronics information). '7 The issue for this report is how much ability in this fourth domain of technical knowledge and skills contributes to the predictive validity of the ASVAB beyond what is contributed by the more academically and cognitively oriented domains.[18]

The actual content of the tests for technically oriented aptitudes is illustrated in box 5-A. The test questions shown indicate the nature of the knowledge and skills tested in these areas.

Hunter et al. have asserted that the 10 aptitude domains of the ASVAB can be reduced to only 1 factor of general ability, because they do not contribute separately to the predictive power of the ASVAB across different military occupations.[19] Their research shows that statistical differences in the numbers of individuals sampled and other such 'artifacts' of the research designs account for all of the differences previously found in the ability of subtests of the ASVAB to predict performance among occupations. By correcting for all of these statistical artifacts, no more variance in performance scores could be explained using separate scores on the 10 different subtests than could can be explained by a single

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14 D. R. Divgi and Paul W. May berry, *7'h, Role of Aptitude Factors in Predicting Hands-on Job Performance*, CRM 69-215 (Alexandria, VA: Center for Naval Analysis, March 1990), p. 5; and Lauress Wise. "The Validity of Test Scores for Selecting and Classifying Enlisted Recruits, " *Test Policy in Defense: Lessons From the Military for Education, Training, and Employment,* Bernard Gifford and Linda C. Wing (eds.), National Commission on Testing and Public Policy (Boston, MA: Kluwer Academic Publishers, 1994), table 15, pp. 221-260.

15 John E. Hunter, "A Causal Analysis of Cognitive Ability, Job Knowledge, Job Performance, and Superior Ratings," *Performance Measurement and Theory*, F. Landy et al. (eds.) (Hillsdale, NJ: Erlbaum, 1993). See also Wigdor and Green (eds.), op. cit., footnote 6, table 8- 10; and May berry, op. cit., footnote 12, table 3.

16 Paul W. Mayberry, *Analysis and Prediction of Infantry Unit Leaders' Performance*, CRM 91-99 (Alexandria, VA: Center for Naval Analysis, June 1991), figure I; and May berry, op. cit., footnote 12, figure 1.

17 Peter H. Stoloff, *Factor Analysis of ASVAB Form 8a in the 19&l DOD Reference Population*, CNA Memorandum 83-3135 (Alexandria, VA: Center for Naval Analysis, August 1983).

18 The ASVAB currently has no test for perceptual-psychomotor or spatial abilities, as do other aptitude tests like the General Aptitude Test Battery. Consideration is being given to adding "assembling objects '' as a spatial reasoning test to the ASVAB.

19 John E. Hunter et al., ''The Validity of the Armed Services Vocational Aptitude Battery (ASVAB) for Civilian and Military Occupations, ' U.S. Air Force Contract No. F416689-83-C-0025, August 1985. See also Lee J. Cronbach, "Five Perspectives on Validity Argument, " *Test Validity*, Howard Wainerand Henry J. Braun (eds.) (Hillsdale, NJ: Lawrence Erlbaum Associates, 1988), pp. 3- 18; Cronbach, op. cit., footnote 1, pp. 293-398; and Malcolm Jones and James A. Eacles, "Predicting Training Success: Not Much More Than g," *Personnel Psychology*, vol. 44, 1991, pp. 321-332.

Box 5-A-Examples of the Content of Test Items on Subtest of the ASVAB for Broad Technical Skills

Auto and Shop Information-

- A car uses too much oil when which parts are worn?
  (a) pistons (b) piston rings (c) main bearings (d) connecting rods
- The saw shown above is used mainly to cut:
  (a) plywood (b) odd-shaped holes in wood (c) along the grain of the wood
  (d) across the grain of the wood

Mechanical Comprehension-

- In this arrangement of pulleys (a system of pulleys with different diameters is shown), which pulley turns faster?
  (a) pulley A (b) pulley B (c) pulley C (d) pulley D
- Which post holds up the greater load? (a load atone end of a beam supported by two posts is shown)
  (a) post A (b) post B (c) both equal (d) not clear

E/ectronics /nformation-

- Which of the following has the least resistance?
  (a) wood (b) iron (c) rubber (d) silver
- In the circuit shown (a battery connected to a resistor) the resistance is 100 ohms and the current is 0.1 amperes. What is the voltage?
  (a) 5 (b) 10 (c) 100 (d) 1,000 *Volts*

SOURCE: U.S. Department of Defense, Defense Manpower Data Center, *Counselor Manual for the Armed Services Vocational Aptitude Battery,* DOD 1304.12-L-ASTP-CM (North Chicago, IL: U.S. Military Entrance Processirrg Command, July 1992), pp. 131-135.

factor of general ability. This is called the validity generalization hypothesis.

More recent research using new hands-on measures of job performance contradicts this hypothesis with regard to technical aptitudes. This newer research shows that the contribution of technical aptitude to the predictive validity of the overall test battery is significant. This implies that the technical aptitude measured by the ASVAB is different from the more purely cognitive and academically oriented areas of the test. Using new testing methodologies developed for the Marine Corps Job Performance Measurement Project, which was overseen by a committee of the National Academy of Sciences, Divgi and May berry have recently found in a study of Marine personnel that the technical aptitude composite of the ASVAB explains 10 percent of the total variation in performance explained by the whole test.[20] The statistical model they used first accounts for all of the variation in performance that can be accounted for by one general factor of ability and then, secondarily, for all of the additional variation that can be accounted for by a composite of the three technical domains considered together (auto and shop information, mechanical comprehension, and electronics information). This is a conservative estimate of the separate effects of the technical aptitude composite on performance. They conclude that one of main reasons why Hunter et al. found that general ability accounts for all of the variance in performance scores is that they used grades in training school as their criterion variable rather than hands-on performance tests. When grades in training school are used as the criterion variable,

[20] Divgi and May berry, op. cit., footnote 14, table 2.

Divigi and May berry find that the technical composite adds little to the predictive validity of the ASVAB.[21]

Similar results were found in another study of Marine infantry by the National Academy of Sciences. When job knowledge tests were used as the criterion variable, the three major, "non-speeded' factors of the ASVAB have about the same predictive validities of about 0.73 (the three non-speeded composites are mathematical, verbal, and technical aptitude) .22 When hands-on performance tests are used, the predictive validities of the same three factors varied significantly. The correlation of technical aptitude with the hands-on performance test results was the highest among the three composites at 0.65, while the other two were about 0.57.

The validity of the ASVAB for predicting performance in mechanical occupations in the Marines has been studied by Mayberry and Carey. They find that, for hands-on performance tests, the predictive validity of the mechanical maintenance composite of the ASVAB used by the Marines[23] averaged 0.068 higher than the next best composite, which is General Technical (GT),[24] and over 0.15 higher than the Armed Forces Qualification Test (AFQT), which is a measure of general ability used by the military .25 These translate to an average of 11 percent above GT and 30.6 percent above the AFQT. The other composites were clerical and electronics.[26] No such differences were found in predicting job knowledge test scores or grade point averages in training school. In other words, the technical aptitude measured through performance tests is different from general intelligence, while the technical aptitude measured through written job competency tests or grades in training school is not.

Another source of evidence for the differential validity of the ASVAB can be obtained by comparing the predictive validity of the subtests across occupations, as shown in figure 5-1. The validities of the different subtests are higher in occupations where the nature of the job tasks corresponds with the nature of the subtest. Evidence like this does not prove the differential validity of the ASVAB but strongly suggests that it exists.[27] For infantryman, there are few differences in predicted hands-on performance among the 10 individual subtests, except for mechanical comprehension, which is noticeably higher than the rest. This agrees with the findings of Mayberry and Carey. For administrative occupations, the validities of arithmetic reasoning and mathematical knowledge are substantially higher than for all of the other subtests and the other occupations. For mechanical jobs, the technical composite is by far the highest and all of the other validities are lower than for all other occupations.

These results from psychometric studies have been confirmed using wage data for civilian occupations. Using the National Longitudinal Study, one researcher found that both wages and earnings in civilian occupations are significantly correlated with scores on the mechanical, elec-

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21 Ibid., p. 9.

22 Wigdor and Green (eds.), op. cit., footnote 6, figure 8-4. The study was based on P.W. May berry, *Interim Results for Marine Corps Job Performance Measurement Project,* Research Memorandum 88-37 (Alexandria, VA: Center for Naval Analysis, 1988).

23 The mechanical maintenance composite consists of the total AS VAB scores for arithmetic reasoning, auto and shop information, mechanical comprehension, and electronics information.

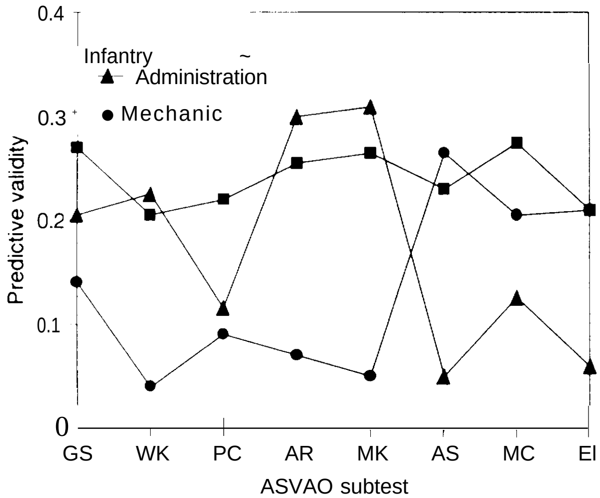
24 The General Technical composite consists of arithmetic reasoning, word knowledge, paragraph comprehension, and mechanical comprehension.

25 May berry and Carey, op. cit., footnote 10, table 13. The predictive validities of the mechanical composite were 0.64 or greater for four of the five mechanical occupations studied and one validity was 0.70.

26 Clerical consists of the mathematics knowledge, word knowledge, paragraph comprehension, and code speeding subtests, and electronics is arithmetic reasoning, general science, mathematics knowledge, and electronics information.

27 Wigdor and Green (eds.), op. cit., footnote 6, p. 171.

Figure 5-l-Correlations of ASVAB Tests With Hands-On Performance Test Scores
(Army occupations)



KEY:

GS = General science
WK = Word knowledge
PC . Paragraph comprehension
AR = Arithmetic reasoning
MK . Mathematics knowledge
AS = Auto/shop
MC . Mechanical comprehension
El = Electronics informatlon

SOURCE: Alexandra K. Wigdor and Bert F. Green, Jr. (eds.), *Performance Assessment for the Workplace, Vol. I* (Washington, DC: National Academy Press, 1991), p. 171.

tronics, and shop information subtests of the ASVAB.[28] No effects were found for scores on the academic and cognitive subtests, but they are highly correlated with years of schooling, which were included in the analysis as a control variable. The independent correlation of the technical aptitude with wages provides strong indication of its independence of the academic and cognitive aptitudes of the ASVAB.

Considered altogether, these studies provide substantial evidence that the technical aptitude measured by the ASVAB, whose content is represented by the test questions in box 5-A, is significantly related to job performance and substantially different from academic and purely cognitive aptitudes.

OCCUPATIONAL MAPS

A second concept of broad occupational skills is being developed by the American Electronics Association (AEA) with support from the U.S. Department of Labor. The effort is one of several pilot projects being supported by the Departments of Labor and Education to develop and demonstrate the feasibility of industry skill standards. In these projects, grantees are urged to organize their standard-setting efforts around what the government has called ‘‘broad occupational areas. For the purposes of this report, the approach will be called “occupational mapping. ’

AEA’s approach to skill standards involves reconstructing the job competency model around generically defined job tasks that cut across a range of occupations, and including categories of related knowledge and technical skills. The new model is intended to provide the industry with the means to ‘‘speak with one voice’ on the skills needed for careers within industry and yet reflect the major differences in specific contexts of employment and jobs. Under the approach, it must be possible to demonstrate the technical accuracy of the resulting skill standards—that the standards are related to high performance in the workplace. The skill standards are also expected to be useful for a wide variety of human resource planning and development needs within the industry other than certification of the competence of individuals.

The orientation of the AEA approach to defining job tasks is borrowed from the job competency model. However, the tasks are identified from the top down within broad clusters of industry jobs rather than the bottom up within narrow categories as in the job competency model. For the AEA project, three broad clusters of occupations have been chosen: manufacturing specialist, pre- and post-sales analyst, and administrative/information services support analyst. AEA estimates that employment in these

28 John Bishop, Center for Advanced Human Resource Studies, Cornell University, ‘‘Educational Reform and Technical Education,” working paper No. 93-04, 1993.

Box 5-B--Broad Occupationai Tasks for Manufacturing Specialists

Key Purpose

Develop, manufacture, deliver, and improve electronics-related products and processes that meet or exceed customer needs.

Critical Functions

Ensure production process meets business requirements.
Initiate and sustain communication processes and procedures.
Establish customer needs.
Determine design workability and manufacturability.
Use human resources to manage work flow.
Select, obtain, and optimize available machines and equipment to meet product process requirements.
Make products that meet customer specifications.

Includes Jobs **Such as**

Production associate, operator, production technician, and assembler.

Scenario

Manufacturing specialists are on the front line of the manufacturing operation. They work as individuals, or increasingly, as members of "self-managed" teams. They often play a key role in work scheduling and resource management within their work group.

They use a variety of quality, cost-reduction, and cycle-time productivity tools and processes. Their direct communication with internal and external customers and other specialist staff is increasing.

SOURCE: American Electronics Association, draft internal memorandum, November 1993.

three occupational areas covers about 60 percent of all jobs at skill levels not requiring a baccalaureate degree in the computer, software, semiconductor, consumer electronics, and telecommunications industries.

This "mapping" of the broad occupational clusters into tasks is done by industry representatives. The process involves first identifying the major purpose of work in each area and a limited number of ''critical functions' defining the content of work output. An example of the major purpose and the critical functions for manufacturing specialists is shown in box 5-B.

The next step in the mapping process is to identify a limited number of activities that must be performed in order to achieve each of the critical functions in the cluster area and explicit criteria for knowing when the activities are being performed well. These criteria will provide the basis for setting performance-level standards for particular jobs within the three broad industry clusters. The specific standards adopted will differ among job areas and segments of the industry, but will remain consistent within the task-oriented framework. In the end, the mapping process will result in skill definitions similar to the job competency model, but guided by a framework of critical functions and performance criteria. Each critical function, together with the associated set of activities and performance criteria, is called a competency module. These competency modules will be the basic unit of skill certification. An example of the competency module for the second critical function of manufacturing specialists is shown in box 5-C.

The criteria defining when critical functions are performed well are one of the major ways in which the occupational mapping strategy of AEA differs from the job competency approach. In the job competency model, the criteria are frequently

Box 5-C--Activities and Performance Criteria for Manufacturing Specialists: Ensure Production Process Meets Business Requirements Competency Module

Integrate Improvement Process Into Each Critical Function

- Quality monitoring and improvement processes are performed and are documented according to company procedures.
- Deviation and root cause of deviation are identified from ongoing analyses of processes.
- Recommendations for process improvement are documented, approved, and implemented.

Meet Health, Safety, and Legal Requirements With Regard to Process, Product, and People

- Health and safety requirements and procedures are implemented and followed at all times.
- Potential health and safety hazards are identified through continuous safety review.
- Confidentiality of proprietary information is protected according to company policy.
- Company standards of business conduct are followed.

Select Setup and Perform Diagnostic Tests

- The selected test method meets product specifications and customer requirements.
- The test method is safe, cost-effective, and meets time needs.
- Equipment setup conforms to required test and space specifications.
- Test equipment is calibrated correctly and functions according to specifications.
- Proper handling procedures are followed.
- Tests and test documentation are completed according to prescribed sequence, time, and quality requirements.
- Test results and serialization of tested products are accurately documented.

Analyze and Interpret Test Data for Problems That Require Corrective Actions and for Compliance With Specifications

- Products or process deviations and root causes of deviations are accurately identified and documented, and corrective action is initiated.
- Systems for evaluating remedial action are established.
- Corrective action and appropriate recommendations are documented.
- Products forwarded to customer on a "conditional accept" basis are accompanied by accurate documentation completed to customer specifications.
- Tests are in compliance with legal requirements, company policy, and customer specifications.

SOURCE: American Electronics Association, draft internal memorandum, November 1993.

only restatements of the tasks,[29] or a set of simple terms such as "skilled,' ''moderately skilled, ' or "unskilled,'* as was discussed in chapter 3. This aspect of the occupational mapping approach provides a clearer methodology for setting performance-level standards than does the job competency method.

As indicated by the manufacturing specialist example, the broad task structures being identified by AEA are also different from the job competency model in the extent to which they reflect the basic concepts of high-performance work systems. The overall structure of the critical functions for manufacturing specialists clearly reflects, for example, the responsibilities being given to front-line workers for monitoring quality, continuous improvement, and dealing with customers.

The next phase of the AEA project will be to identify the categories of technical skills, knowledge, and understanding that underlie performance of the critical functions. In these areas, AEA

[29] For example, if the task is "prepares checklists,'' the criteria is ''prepared checklists. '

will incorporate methodologies for measuring skills and abilities, as discussed in other sections of this chapter. These could include ways to measure the technical knowledge or aptitudes of individuals, or their cognitive skills. This knowledge and underlying capabilities aspect of occupational mapping indicates how the technique may provide a framework for integrating different approaches to broad occupational skills. It also is where AEA is considering how the skills structure can relate to the K-12 system of education. Similar approaches to the definition of broad occupational skills have been followed in Great Britain and Australia.

CORE OCCUPATIONAL SKILLS

As shown in figure 3-9 in chapter 3, five states are planning to adopt or have adopted some strategy for organizing their programs of vocational education around broad technical skills. In most of these cases, the strategy adopted by the state is to divide vocational education into broad clusters of occupations and, in the early years of preparation, organize students' programs around the development of some set of core occupational skills. Each core area of knowledge and skills then branches at the next step into sequences of clusters of courses that become increasingly more specialized. Some examples of these broad cluster areas are the traditional areas of business, agriculture, and health. States typically have 6 to 10 cluster areas covering all industries.

New York was the first state to adopt such a statewide policy, starting in 1983.[30] Through a long process of planning and development, a ''continuum' of occupational education was adopted. A key aspect of the continuum is that, starting in the earliest grades and continuing throughout high school, the occupational curriculum is guided by learning objectives in five broad areas:

1. personal development (e.g., the development of a positive self-concept, learning to work in groups, and learning how to find a job);
2. social systems (e.g., understanding the economics of business and the legal system);
3. information skills (e.g., communicating orally and using computers to present information);
4. resource management (e.g., managing money and time); and
5. technology (e.g., understanding systems in manufacturing, construction, communications, and agriculture).

Occupational education starts in the elementary grades with courses in the use of computers. By the end of the 8th grade, all students must have taken required courses in keyboarding and computer literacy, home and career skills, and Introduction to Technology.[31]

All students who decide to major in vocational education are then required to take a 1-year course in the Introduction to Occupations. This course is organized around the five core occupational competencies, with an emphasis on employability and other generic workplace skills in the first half of the course and more occupationally specific knowledge and skills in seven occupational cluster areas in the second half. In the first half of the Introduction to Occupations course, students take units in the economics of business and personal finances, human relations, decision making and problem solving, energy systems, and other topics. The seven cluster areas that start in the second half are agricultural education, business/marketing education, health occupations education, home economics education, technical educa-

[30] This description of the New York program is based on Richard Jones, former Director of the Division of occupational Education instruction, personal communication, Aug. 24, 1993.

[31] The Introduction to Technology" course is similar to the curriculum described in the next section on Design and Technology, but the focus is on learning about the systems of technology.

tion, technology education, and trade and industrial education. In agricultural education, for example, there is a module in the second half of the Introduction to Occupations course on plant science that covers the basic biology and agronomy of plants (seeds, roots, leaves, stems, and flowers), life supporting processes and reproduction, environmental factors, soil and fertilizers, plant pests, and so forth. Following the Introduction to Occupations course, students take a subject area core course and sequences of three or more increasingly more specialized courses in one of these seven cluster areas. Instruction at these more advanced levels is still guided by the same core occupational skills but at more advanced levels of learning.

An assessment program has been implemented to sustain the teaching of the core occupational competencies throughout the curriculum. The test for the Introduction to Occupations course consists of a locally administered but state-developed competency test. The state requires that all students who complete the course take the test. The state also has competency tests in four of the seven occupational cluster areas, which are taken on completion of required coursework in those areas.

California is in the process of developing and implementing a similar approach to organizing vocational education around core skills and occupational clusters. For example, in business education, which is serving as a model for the other cluster areas, a framework of curriculum standards will soon be adopted for the first year course of the program. This course is called the business technology core. After completing the business technology core, students will choose one of four ‘‘career path clusters’ in computer science and information systems, business administration, accounting and finance, or marketing. Three sequential levels of learning outcomes are planned within each cluster; these will be adopted as a series of standards. There will be career path cluster standards, career path specialization standards, and an entrepreneurship standard. The business technology core will also be linked to instructional units or courses in business exploration planned in the upper elementary grades.

Cutting across all of these cluster areas in the business program will be the career performance standards in communication skills, employment literacy, interpersonal skills, occupational safety, personal skills, technological literacy, and thinking and problem-solving skills that are described in box 3-A in chapter 3. The assessment of these career performance standards will be part of the new statewide system of assessment for vocational education that will consist of student portfolios and on-demand assessment (also described in box 3-A).

This core occupational skills model of New York and California is similar to the reorganization of the German apprenticeship system that has occurred over the past 10 years or so to broaden the skill content of the training. A similar branching structure of broad occupational areas that divide into specialties over the 3-year course of an apprenticeship program has been adopted.

DESIGN AND TECHNOLOGY

The fourth approach to defining broad technical skills is to view technology itself as something that is worthwhile for all students to learn about, and not just students who are headed for work or 2-year programs. From this viewpoint, learning about technology as a product of human civilization as well as developing the capability for actually using it to accomplish practical purposes should be part of the education of all students. starting in the early grades. Involving all students in learning about technology and how to use it could help to erase some of the distinctions often made in schools between students headed for college and working with their minds, and those destined for working with their hands. Increasingly, technology itself is blurring this distinction. Teaching technology to all students in this way frames the issue of who needs what technical skills in the broadest possible terms; capabilities for design and technology are needed to some extent by everyone. At the same time, if started early enough, technology education could help to motivate students toward pursuing technical careers and provide them with foundations of knowledge and capabilities for converting thought into action.[32]

A variety of different forms of technology education exist in the United States and abroad. One version may offer considerable potential for helping all students develop broad technical skills. In Great Britain, this new form of technology education is known as design and technology. It has developed over the past 20 years and is now 1 of the 10 major subjects of the new national curriculum of the British schools.

The significant term is ''design. ' In design and technology, students learn as much or more about becoming a designer as they do about the workings of the technology itself. Becoming a designer involves acquiring three kinds of knowledge and capabilities:

1. procedural knowledge of how to design;
2. capability of communicating complex ideas with clarity, confidence, and skill; and
3. conceptual knowledge and understanding of the use of materials, energy systems, and aesthetics in designing and building technological systems—along with knowledge and awareness of people and their needs.

The procedural knowledge of design involves learning how to discern needs and thoroughly investigate them as an architect or engineer would, prepare a design brief or plan for meeting those needs, generate ideas and develop them into a design, build the design, reflect on the quality of the result in meeting the original needs, and then act on the reflection to produce a better design. The subject is taken by both boys and girls, and both high and low ability students, beginning in the first grade. It is conducted to appeal to all students—those oriented mainly to the humanities, and those more scientifically or technically inclined.

Learning how to design involves learning how to think concretely in complex situations. It involves using knowledge and logical thinking to produce better designs. It also involves making choices and weighing the desirability of alternative designs from social, economic, aesthetic, and human points of view, as well as from the perspective of producibility.

A thoroughly developed performance assessment in England has shown the effectiveness of the design and technology curriculum for teaching students how to become designers. Normally, girls perform better than boys on the design tasks of investigation and reflection, while the boys excel at developing designs and building them into final products. Lower ability students tend to be better at design tasks that are tightly structured, and higher ability students tend to be better on more openly structured tasks. However, a clear finding of the assessment is that the more students have been exposed to design and technology, the smaller these differences become.

The assessment also showed the interdependence of thinking and doing in technology. Students given the same set of five assessment tasks but in different order were much better able to identify the strengths and weaknesses of an original design when they had previously been given a task of actually designing an improved product. Providing students with a brief period of discussion midway in the development of a design, where the students described their plans and received peer comments, immensely improved the quality of their final products. The assessments showed no simple relationships between sequences of design steps and thought processes that lead to quality results, and those that do not. In other words, the process of design

32 This section draws on Richard Kimbell, University of London, Goldsmith's College, "Technology in the School Curriculum, " OTA contractor report, October 1993. This contractor report is available from OTA's Education and Human Resources Program.

cannot be reduced to a checklist or a methodical series of steps.

COGNITIVE SKILLS

Finally, a fifth approach to defining broad technical skills is the concept of cognitive skills. This concept comes from cognitive science research on problem solving and trouble shooting in a range of occupations, apprenticeship learning, and learning in academic subjects. Much of the research has been generated by efforts to explain the differences between the cognitive skills of experts and novices,

This research shows that experts draw on tightly integrated structures of procedural and conceptual knowledge. This knowledge is also highly contextualized; it is specific to the particular organization and technological environment of the expert. Over time, this knowledge becomes schematically organized, according to specific problems and situations—it is not abstract. This schematic knowledge enables experts to understand the complex relationships necessary for skilled performance. Experts differ profoundly from novices in the speed with which they can access this knowledge; a novice must try to solve each problem de novo.[33]

Substantial proportions of the knowledge of experts are procedural and tacit; experts know what to do and when, but they cannot always express what they do exactly. Their procedural knowledge, together with the conceptual and contextual knowledge underlies what scientists call metacognition—the ability for goal setting, planning, adaptation, and learning that allow for expert problem solving.[34]

Cognitive skills are acquired in stages. Initially, a skill is heavily dependent on declarative (verbal) knowledge. In the declarative stage, the learner either encounters or is instructed in the facts and procedures relevant to the execution of a particular skill.[35] These facts are stored in memory as statements, which can be verbalized and recalled one-by-one as required. The novice uses this knowledge interpretively-that is, the novice might say: "The situation is 'a,' therefore I should do 'b. ' " The novice then would be able to do "b.' ' In this declarative stage, general problem-solving strategies are employed by the novice to organize these steps and bring each one into play until the problem is solved or the goal is reached. An example of such a general, or ''weak method, ' strategy is solving problems by analogy, or mimicking the steps that were followed in successfully solving an apparently similar problem. The strategy is general because it does not depend on knowledge of the area in which it is being applied. "Strong methods" are specific to a domain and are heavily dependent on knowledge of it.

The second stage is "skill automation" or compilation of the cognitive skill. In skill automation, weak methods of problem solving are transformed into strong methods.[36] This occurs through gradual transformation of the factual and conceptual knowledge acquired in the declarative stage into a procedural form that is highly organized so that it can be accessed and used with minimal conscious reasoning activity.[37] The skill becomes "automatic" and the load on working memory of recalling the specific steps involved becomes much less. The skill can be performed

33 Robert Glaser et al., ''Implications of Cognitive Psychology for Measuring Job Performance," in Wigdor and Green (eds.) op. cit., footnote I 2, pp. I -2.

34 Ibid.

35 James M. Royer et al., ''Techniques and Procedures for Assessing Cognitive Skills, *Review of Educational Research*, vol. 63, No. 2, summer 1993, p. 204.

36 J.R. Anderson, ''Skill Acquisition: Compilation of Weak-Methods Problem Solutions,'' *Psychological Review*, vol. 94, No. 2, 1987, pp. 192-210.

37 Royer et al., op. cit., footnote 35, p. 206.

without consciously thinking about it and the speed increases. Studies of apprenticeship have shown that this compilation process is aided by: a) situated learning, where students execute tasks and solve problems in a real environment where the purposes of the knowledge are clear; b) external support, or "scaffolding,' available from a tutor or master to model the ideal performance, support learning, and supply missing pieces of knowledge; c) fading, or withdrawal of support, as the skill is acquired; and d) learning activities that are carefully sequenced to be both sensitive to student needs and robust enough to foster integration and generalization of the skill.[38]

The third stage is skill refinement, or proceduralization, which is a continuation of the compilation process of the second stage. In this stage, performance of the skills is speeded up by weeding out nonessential steps and strengthening associations between events that may occur in performing the skill and effective actions in response to them.[39] As a result, performance ' f the skill becomes much more sensitive to small but critical situational differences and the flexibility of response to unexpected situations or new data greatly increases.

This model of skill acquisition has been shown to account for many of the differences in the cognitive skills of novices and experts, and to accurately describe the learning processes through which the skills are acquired.[40] The model has been applied in a wide range of domains from electronics troubleshooting, power plant control, and financial planning to tennis.

The knowledge of experts is thus highly procedural and integrated in nature rather than conceptual and detached from contexts of use, as is so much of the learning process and the knowledge acquired in school. Facts, routines, and concepts are bound together with rules for their application and to conditions under which the knowledge is useful.[41] The knowledge is highly goal oriented and conditional. It includes knowledge of specific goals and interrelated subgoals, methods that are employed in pursuing those subgoals, selection rules for choosing subgoals, evaluating methods based on experience, and prerequisite cognitive skills. For example, the goal of the relatively simple cognitive skill in word processing of moving text from one point in a document to another point can be broken down into a conditional series of subgoals and procedural steps. (To move a block of text from A to B, first block the text to be moved, then choose the ''move' operation from the menu, and so forth). Experts have been shown to be much better at identifying the hierarchy of subgoals, or intermediate steps, for accomplishing such tasks than novices. In the language of cognitive science, experts are much better than novices at mapping the ''problem space' of procedures to employ in solving a problem or generating an idea and deciding on the order. Novices, for example, may not be able to identify the problem space or structure of goals, and simply try the few procedures they know one by one to see which one may work. Selection rules refer to the knowledge acquired by the expert of the particular conditions under which specific procedures should be employed. Prerequisite skills could be, for example, capabilities for performing all of the measurements needed in executing a procedure.

Cognitive research has shown that the organization of the knowledge structures of experts is what explains the flexibility and speed with which they are able to access knowledge and use it. One of the profound aspects of the knowledge organization of experts is their 'depth of problem

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[38] Sherrie P. Gott, "Apprenticeship Instruction for Real-World Tasks: The Coordination of Procedures, Mental Models, and Strategies, " *Review of Research in Education,* vol. 15, 1988, p. 99.

[39] Royer et al., op. cit., footnote 35, p. 206.

[40] Glaser et al., op. cit., footnote 33.

[41] Ibid., p. 7.

representation. .‘ Using their stored knowledge, experts are able to rapidly induce principles from the given features of problems and then represent the problems in terms of these principles. This gives them quick access to patterns of events and associated sequences of preferred moves and procedures. They are able to do this because they do not have to first load this knowledge into their working memory before they are able to access it and use it. The problem representations of novices, on the other hand, tend to be expressed in terms of literal objects, the surface features of problems, or the events given explicitly in a problem statement.[42]

One example of the depth of problem representation of experts is ‘‘chinking. ’ For example, expert electronics technicians have been shown to be much better at reproducing circuit diagrams flashed before them for a brief period of time than novices, but only when the circuits are correct. When the circuits are wrong, there is no difference between experts and novices in their ability to reproduce the diagrams.[43] Skilled electronics technicians also tend to reconstruct symbolic drawings of circuit diagrams they are working with according to the functional nature of the elements in the circuit, while novices tend to reproduce the circuits based on the spatial proximity of the elements. The “chunks’ of knowledge they draw on to produce these diagrams tend not to reflect knowledge of function.[44]

In addition to the contextual and procedural knowledge in the knowledge structures of experts is a third component, the capability for visualizing or mentally modeling the features or operation of the technological devices or systems, or representing the problem space of interpretations and conceivable actions. These mental models provide essential connections between the procedural and contextual knowledge, enabling the expert to relate knowledge of one form to the other and build representations of the situations at hand.[45] These visual representations help to overcome the limiting serial nature of language and procedural knowledge to provide more adequate means of explaining or interpreting complex and/or dynamic phenomena encountered.[%] An important finding in studies of the diagnosis of x-rays by physicians, for example, shows that experts have a reservoir of preexisting schemata in their heads of normal and abnormal configurations of the organs or tissues that are triggered early in a diagnosis.[47] The diagnosis involves fitting the schemata to the present case until the most consistent explanation is found.

Mental models are essential for effective causal reasoning about the sources of problems and potential solutions. Studies of experts have shown how much better they are than novices at visualizing the systems with which they are working at different levels of abstraction and working back and forth across these levels of abstraction to invoke the level of analysis most appropriate for the diagnosis or task at hand.[48] For example, in diagnosing a broken piece of equipment, experts may employ their schematic knowledge of the functions of the equipment and its components, factual knowledge about the operational characteristics of the individual components, and orderings of how observed symptoms of one kind are conditionally related to others. Much of this reasoning about problems tends to be qualitative

42 Royer et al., op. cit., footnote 35, pp. 217-222.

43 Ibid., p. 218.

44 Robert Glaser, ‘‘Expertise and Assessment,’’ *Cognition and Testing*, M.C. Wittrock and E.L. Baker (eds.) (Englewood Cliffs, NJ Prentice Hall, 1991), pp. 17-30.

45 Glaser et al., op. cit., footnote 33, p. 3.

46 Gott, op. cit., footnote 38, p. 123.

47 Glaser et al., op. cit., footnote 33, p. 9.

48 Gott, op. cit., footnote 38, p. 124.

in nature rather than quantitative (e.g., “if the signal is present there, then it should be present here’ ‘). Overemphasis on quantitative reasoning in the early stages of acquiring skills has consistently been shown to inhibit understanding of the causal principles involved.[49] For example, students in the physical sciences who have mainly studied in the traditional modes of highly quantitatively oriented instruction have consistently shown deficiencies and mistakes in their understanding of the underlying causal principles in a domain.[50]

A number of experimental efforts have been undertaken to build computer-based tutors for training experts based on these concepts of the nature and acquisition of cognitive skills. Evaluation of the effectiveness of these tutors has shown the strongest results for systems that coordinate the teaching of contextual and procedural knowledge so that the uses of visualization and modeling in problem solving are made explicit.[51] Tutors that mainly support the acquisition of procedural knowledge yield trainees who are less able to deal with complexities and uncertainty. Such training has usually been found to be even less effective and efficient than methods of informal observation on the job. A related finding is that the presentation of “. . . abstract representations of device interdependencies for learners to inspect and manipulate seems central to the development of envisioning capabilities. ’ ’[52]

This model of the acquisition of cognitive skills has important implications for broad technical skills. The cognitive model supports the job task and procedural orientation of job competency approaches over attempting to teach or assess general abilities directly, as implied by the vocational aptitude and core occupational skills approaches. At the same time, the model implies that the limitation of learning to the rote memorization of procedures within a fixed and narrow task environment without the simultaneous introduction of concepts and support for modeling and visualization will inhibit the development of expertise and result in trainees who are not capable of responding flexibly to new problems. The model therefore suggests that the teaching and assessment of broad technical skills should include methods of eliciting respondents’ capabilities for visualizing and conceptualizing problems in context, and not just recalling facts from memory even if the facts are closely related to those contexts and demonstrate mastery of procedures. The model does not support decontextualized approaches to the assessment of broad technical skills, like those employed in traditional testing for vocational aptitudes or multiple abilities, and especially not at expert levels of performance. The decision orientation of the model strongly suggests that the assessment of broad technical skills should include strategies for assessing metacognition—the capability to choose among goals and methods and alternative interpretations of evidence in different contexts.

The cognitive model also strongly suggests that assessment should focus on both the procedural and conceptual aspects of broad technical skills in authentic contexts, rather than the recall of isolated bits of knowledge on demand. Reliance should be placed on using multiple methods of assessment rather than written testing, although both may be needed. The highly integrated and contextualized nature of the process of knowledge compilation lying at the heart of the cognitive model implies that learning broad technical skills must also be active, so that students are constructing knowledge for them-

49 Ibid., p. 127.

50 Ibid Also see Howard Gardner, *The Unschooled Mind: How Children Think, and How Schools Should Teach* (New York, NY: Basic Books, 1991).

51 Gott, op. cit., footnote 38, p. 161.

52 Ibid.

selves, gaining facility in integrating it from different sources, and using it for practical ends.

Finally, the cognitive model raises a caution flag against the possibilities of broadening skill definitions and methods of assessing and certifying them simply through expanding indefinitely the job and task environments in which they apply. The reason for this skepticism is the prominent role of contextual knowledge in the development of expertise, and the highly organized and tightly coupled ways in which the knowledge of experts is structured.

A different model of how to achieve breadth of skill is suggested by the cognitive model in which breadth is achieved through depth. The view is that the best way to achieve breadth of skill in the long run is through deepening knowledge development within a limited number of areas of specialization, rather than attempting to take on ever wider circles of problems. The concept is achieving "breadth through depth" rather than breadth alone. The problem with the breadth through depth approach is that expertise developed through specialization and depth of pursuit can be ' 'brittle; it does not transfer well to new situations and new kinds of problem environments. When confronted with new problems in unfamiliar areas, the narrowly trained learner can be immobilized and incapable of responding productively. In order to achieve breadth, the strategy of developing and assessing depth must be coupled with considerable experience in dealing with new problems and novel situations.

Cognitive theory is not very helpful so far in prescribing exactly how transfer occurs and beyond that how learning should occur in order to maximize capacity for transfer, except to say that the knowledge and skills acquired will be brittle if learners are not confronted with novel problems to solve within their domains of expertise and in related domains. In this light, breadth of skill becomes the individual's capability for using knowledge from domains in which one is expert in new domains. Whether knowledge and skills from domains in which one is expert are applied in the new domains as ''finite elements' or instead facilitate the acquisition of knowledge and skills in the new areas is an unresolved issue.

FINAL NOTE

The aptitude model suggests that the ability to transfer expertise in novel situations and to new domains needs to be defined in terms of both demonstrated capacity for responding cognitive] y to new situations and evidence of broader general aptitudes that strongly relate to the ability to transfer and learn in new situations. This melding of two approaches is also evident in the addition of categories of knowledge and skill to the broad occupational tasks that are identified in the approach of occupational mapping.

In the occupational mapping approach, breadth of technical skill is described through identifying tasks presumed to define competencies that cut across a range of occupations and form the core of expertise. Their manifestations may be somewhat different in different job contexts and industry segments but in outline they are similar. The critical role of contextual knowledge in expertise, as described in the section on the cognitive model, indicates that it remains an open question whether individuals who are found to be competent in one job context according to the occupational mapping approach would be able to demonstrate equal levels of the same competencies in other job contexts.

These five approaches to defining broad technical skills provide starting points for moving to concepts that are at once deeper, more unifying, and more specific than the concepts underlying the various approaches. Another need is to become clearer about the content of technical skills and how they differ from other capabilities, such as interpersonal and communications skills, motivation, and academically oriented competence.