PERCEPTUAL AND PSYCHOMOTOR LEARNING IN INDUSTRIAL ARTS EDUCATION

1985

American Council on
Industrial Arts Teacher Education

34th Yearbook

A TRIBUTE TO WILLIAM McKNIGHT JR. and WESLEY D. STEPHENS

The membership of the ACIATE (Past, Present and Future) is indebted to two individuals who have made a monumental contribution during the past 34 years. William McKnight Jr. and Wesley D. Stephens have dedicated endless hours and energy on behalf of the Council since August 9, 1951.

On that date ACIATE President Walter R. Williams Jr. met with these two men in Chicago to discuss a proposal for a yearbook. Out of that discussion came the first Yearbook, *Inventory-Analysis of Industrial Arts Teacher Education Facilities, Personnel and Programs* edited by Walter R. Williams Jr. and Harvey Kessler Meyer. In addition, arrangements were made for subsequent Yearbooks. That arrangement still exists today.

On that very day, William McKnight Jr. confirmed the commitment to the Council in writing. He said, "McKnight & McKnight welcomes an opportunity to contribute in some way to the professional growth of industrial arts education, and in our discussion on Yearbook publication, we feel that we can make a tangible contribution to the worthwhile program you have underway."

This contribution has been phenomenal, including the efforts of 49 editors, 241 authors, as well as all profits from the entire series totalling $56,506.23. Yes, we can quantify such numbers, but there is no way that we can place a value on the personal and professional dedication of these two men. They have shared their insight, their time, their concerns. They have indeed touched the lives of hundreds of readers. Most importantly, their efforts have ultimately touched the lives of thousands of children in industrial arts classes throughout the nation.

William McKnight and Wesley D. Stephens have worked hard for our profession and have never asked for anything in return. The highest compliment that we can give, is to say "thank you" for contributing to the education of thousands of students in industrial arts programs throughout the nation.

The Membership
1951 — Long Range Future

PERCEPTUAL AND PSYCHOMOTOR
LEARNING IN INDUSTRIAL
ARTS EDUCATION

PERCEPTUAL AND PSYCHOMOTOR LEARNING IN INDUSTRIAL ARTS EDUCATION

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University Park, Pennsylvania

34th Yearbook, 1985

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Foreword

Industrial arts educators have consistently been strong advocates of learning in the cognitive, psychomotor, and affective domains. A phenomenal amount of research has been completed to assist the teacher in all three areas. The 32nd yearbook (1984) considered the affective domain and the challenges presented in our discipline. The yearbook you are about to read takes the reader one step further by providing a succinct analysis of perceptual and psychomotor learning in industrial arts education.

"Yearbook 33" provides a succinct overview of perceptual and psychomotor learning by addressing the needs of students as they mature during their school years. Keen insights are provided through the authors' analysis of theoretical models of perceptual and psychomotor learning and analysis of human growth and development. The yearbook goes beyond the theoretical foundations by providing useful information concerning specific activities within the school. Assessment and measurement of skills, instructional strategies and environmental factors are discussed in a way that provides the reader with highly useable information. It should be noted that three contributors of this yearbook are from outside of our discipline. Their contributions to this piece of work are most notable and worthwhile.

The council commends editor John M. Shemick for his contribution as an author and editor. At the same time, the council salutes Bennett & McKnight for its support and contribution to the publishing of this yearbook. Each yearbook is read by hundreds of industrial arts educators and on behalf of all of those professional educators, we want to extend our gratitude and say that we look forward to a long and fulfilling relationship with them.

Donald P. Lauda
President, ACIATE

March 1985

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Yearbook Proposals

Each year, at the AIAA international conference, the ACIATE Yearbook Committee reviews the progress of yearbooks in preparation and evaluates proposals for additional yearbooks. Any member is welcome to submit a yearbook proposal. It should be written in sufficient detail for the committee to be able to understand the proposed substance and format, and sent to the committee chairman by February 1 of the year in which the conference is held. Below are the criteria employed by the committee in making yearbook selections.

ACIATE Yearbook Committee

Guidelines for ACIATE Yearbook Topic Selection

With reference to a specific topic:

1. It should make a direct contribution to the understanding and the improvement of industrial arts teacher education.
2. It should avoid duplication of the publication activities of other professional groups.
3. It should confine its content to professional education subject matter of a kind that does not infringe upon the area of textbook publication which treats a specific body of subject matter in a structured, formal way.
4. It should not be exploited as an opportunity to promote and publicize one man's or one institution's philosophy unless the volume includes other similar efforts that have enjoyed some degree of popularity and acceptance in the profession.
5. While it may encourage and extend what is generally accepted as good in existing theory and practice, it should also actively and constantly seek to upgrade and modernize professional action in the area of industrial arts teacher education.
6. It can raise controversial questions in an effort to get a national hearing and as a prelude to achieving something approaching a national consensus.
7. It may consider as available for discussion and criticism any ideas of individuals or organizations that have gained some degree of acceptance as a result of dissemination either through formal publication, through oral presentation, or both.
8. It can consider a variety of seemingly conflicting trends and statements emanating from a variety of sources and motives, analyze them, consolidate and thus seek out and delineate key problems to enable the profession to make a more concerted effort at finding a solution.

Approved, Yearbook Planning Committee
March 15, 1967, Philadelphia, PA.

Previously Published Yearbooks

*1. *Inventory Analysis of Industrial Arts Teacher Education Facilities, Personnel and Programs,* 1952.
*2. *Who's Who in Industrial Arts Teacher Education,* 1953.
*3. *Some Components of Current Leadership; Techniques of Selection and Guidance of Graduate Students; An Analysis of Textbook Emphases;* 1954, three studies.
*4. *Superior Practices in Industrial Arts Teacher Education,* 1955.
*5. *Problems and Issues in Industrial Arts Teacher Education,* 1956.
*6. *A Sourcebook of Reading in Education for Use in Industrial Arts and Industrial Arts Teacher Education,* 1957.
*7. *The Accreditation of Industrial Arts Teacher Education,* 1958.
*8. *Planning Industrial Arts Facilities,* 1959, Ralph K. Nair, ed.
*9. *Research in Industrial Arts Education,* 1960. Raymond Van Tassel, ed.
*10. *Graduate Study in Industrial Arts,* 1961. R. P. Norman and R. C. Bohn, eds.
*11. *Essentials of Preservice Preparation,* 1962. Donald G. Lux, ed.
*12. *Action and Thought in Industrial Arts Education,* 1963. E. A. T. Svendsen, ed.
*13. *Classroom Research in Industrial Arts,* 1964. Charles B. Porter, ed.
14. *Approaches and Procedures in Industrial Arts.* 1965. G. S. Wall, ed.
15. *Status of Research in Industrial Arts,* 1966. John D. Rowlett, ed.
16. *Evaluation Guidelines for Contemporary Industrial Arts Programs,* 1967. Lloyd P. Nelson and William T. Sargent, eds.
17. *A Historical Perspective of Industry,* 1968. Joseph F. Luetkemeyer, Jr., ed.
18. *Industrial Technology Education,* 1969. C. Thomas Dean and N.A. Hauer, eds. *Who's Who in Industrial Arts Teacher Education,* 1969. John M. Pollock and Charles A. Bunten, eds.
19. *Industrial Arts for Disadvantaged Youth,* 1970. Ralph O. Gallington, ed.
20. *Components of Teacher Education,* 1971. W. E. Ray and J. Streichler, eds.
21. *Industrial Arts for the Early Adolescent,* 1972. Daniel L. Householder, ed.
*22. *Industrial Arts in Senior High Schools,* 1973, Rutherford E. Lockette, ed.
23. *Industrial Arts for the Elementary School,* 1974. Robert G. Thrower and Robert D. Weber, eds.
24. *A Guide to the Planning of Industrial Arts Facilities,* 1975. D. E. Moon, ed.
25. *Future Alternatives for Industrial Arts,* 1976. Lee H. Smalley, ed.
26. *Competency-Based Industrial Arts Teacher Education,* 1977. Jack C. Brueckman and Stanley E. Brooks, eds.
27. *Industrial Arts in the Open Access Curriculum,* 1978. L. D. Anderson, ed.
28. *Industrial Arts Education: Retrospect, Prospect,* 1979. G. Eugene Martin, ed.
29. *Technology and Society: Interfaces with Industrial Arts,* 1980. Herbert A. Anderson and M. James Bensen, eds.
30. *An Interpretive History of Industrial Arts,* 1981. Richard Barella and Thomas Wright, eds.
31. *The Contributions of Industrial Arts to Selected Areas of Education,* 1982. Donald Maley and Kendall N. Starkeather, eds.
32. *The Dynamics of Creative Leadership for Industrial Arts Education,* 1983. Robert E. Wenig and John I. Mathews, eds.
33. *Affective Learning in Industrial Arts,* 1984. Gerald L. Jennings, ed.

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*Out-of-print yearbooks can be obtained in microform and in Xerox copies. For information on price and delivery, write to Xerox University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan, 48106.

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Chapter

Preface

Undoubtedly, the reason for the success of industrial arts through the years is because it has been a program of "learning by doing." However, it has not been without its critics. Many of the negative feelings I have encountered from middle-aged men seem to stem from the shop-foreman mentality of the "shop teacher" of their day. They were teachers who thought that "the more you expect, the more you'll get." In reality, they were teachers who demanded levels of psychomotor excellence beyond the developmental stage of the students in their charge. They seemed to view their program as a kind of apprenticeship training. The failing of students who could not meet their skill requirement was in their mind "maintaining standards."

The profession turned away from this faculty psychology approach to teaching-learning about the time that Gordon Wilber's *Industrial Arts in General Education* was published. Wilber emphasized that success is a spur to learning and failure a brake. Unfortunately, teachers who attempted to set realistic psychomotor objectives had to rely on intuition and personal experience. Researchers in industrial arts also were grasping for structure in the psychomotor domain. Is there still a need? Yes, greater than ever.

With the advent of Public Law 94-142, which provides for education for all handicapped children, increased demands are being made of industrial arts teachers for assessment, diagnosis, and accommodation of special needs learners. Teachers becoming involved in preparing individual education plans (IEP) for "mainstreamed" students must have some knowledge of perceptual and psychomotor abilities as well as human maturation.

This yearbook has been written for teacher educators, researchers and graduate students in industrial arts and industrial education. Hopefully, this volume will help them in the development of curriculum materials directly applicable at the grass-roots level.

John M. Shemick
Editor
University Park

Chapter 1

The Perceptual and Psychomotor Domain: An Overview

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Educational psychologists categorize learning into the three domains: *Cognitive* (knowing), *Affective* (feeling), and *Psychomotor* (doing). While their attention has been focused mainly on the cognitive and affective domains, scholars in other academic fields have had a long time interest in various aspects of the perceptual-motor field. Their interests range from the cognitive (psycho) extreme of the continuum to the neuromuscular (motor) extreme.

In view of these differing interests it should not be surprising to find differences in terminology and approaches to structuring this psychomotor domain. The situation is not unlike the famous Indian legend about the blind men who were taken to "see" an elephant. Each placed his hands on a different part of the elephant, from which experience he generalized about the total animal. One man felt the animal's leg and claimed that an elephant was like a tree. The second felt the tail and insisted that the elephant was like a rope. Another felt the trunk and declared that the elephant was like a snake. While each was partly correct from his limited perception, all were wrong about the elephant's description (Galdone, 1963). Accordingly, while most major approaches to the psychomotor domain have been presented in this chapter, each represents one point of view. Therefore, the terminology used by these groups later in the chapter reflects their particular interest area, but they are all part of the psychomotor domain.

BACKGROUND

Contributing Academic Fields

Experimental Psychology. The history of skills research parallels that of experimental psychology according to Irion (1969). While Woodworth's book *Le Movement* ushered in the study of psychomotor skill acquisition in 1903, it was Hull's work during World War II that sparked the major wave of research studies. This was partly due to his book *Principles of Behavior* which appeared in 1943, but more importantly because of his work with the Army Air Corps with the problem of selecting air crews. Nearly half of the skill research ever published appeared during the 1945-1957 period (Irion, 1969). "The use of motor tasks as a means to an end was a back-door boost for motor-skill research . . ." (Kelso, 1982, p. 4).

Differential Psychology. The testing of inductees into the Armed Forces during World War I stimulated the interests of some psychologists in the identification, description, and measurement of the ways people differ in abilities, traits, aptitudes and interests. Advancements in psychological measurement and data analysis led to the development of the area known as differential psychology. Researchers in this area focused on investigating individual differences and sought to account for them through measurement and interrelating abilities, interests, aptitudes, and personality traits (Landy and Trumbo, 1976). E. A. Fleishman, discussed later in this chapter, is probably one of the most notable of this group with his factor-analytic studies of psychomotor abilities.

Industrial Psychology. While the first formally recognized degree in industrial psychology was granted in 1922, pioneering works by the Galbreths in 1919 on motion analysis, and Taylor's 1911 time analysis studies, had set the stage. Industrial psychology grew from roots in experimental and differential psychology which provided the scientific research traditions needed by professionals to attack problems that people encountered in the work place.

In the past two decades, interdisciplinary groups have given rise to biomechanics (body mechanics), ergonomics (study of the man-machine interface), human factors (study of factors influencing human performance) and psychotechnology (applied experimental psychology). All are interested in the structure of the psychomotor domain.

Need for Structure

Kelso, (1982) makes a case for a classification structure in the psychomotor domain when he says:

> In an attempt to bring order to the area of psychomotor learning, many classification systems have been developed for motor skills. These classification systems, or taxonomies, are important for four reasons. First, they provide a means of bringing order to the very diverse field of motor skills. . . . Second, the actual process of identifying these common elements may further our understanding of motor skills . . . Third, these systems help focus research efforts on those elements . . . Fourth, categorizing motor skills makes it possible to investigate how sample skills from within a category respond to a particular teaching technique (p. 9).

Fleishman (1972), in his study of the feasibility of a general taxonomy for human performance, pointed out that the various potential users of a classification system seek very different information from it (Table 1-1).

Table 1-1
Criterion Measures for Evaluating Potential Classification Systems

TYPICAL USER	USUAL CLASSIFICATION GOAL	USERS' CRITERION MEASURE
Experimental Psychologists	Predicting similar results with two laboratory tasks	Can the system account for the effects of different kinds of stressors on performance?
Personnel Psychologists	Predicting the relative performance of persons in one specified task based on their relative performance in another specified task	Can the system be used to predict factor loadings and validity coefficients?
Human Engineers (Human Factors)	Predicting that equipment design changes in two tasks will have similar results	Can the system be used to predict the result of equipment design decisions (e.g., a decision to color code or subgroup dials . . .)?
Educators & Trainers	Predicting the program design decisions in the training programs for two tasks will have similar results	Can the system be used to predict the result of training-program design decisions (e.g., increase or decrease in number of hours of training, use of simulators, etc.)?

(Fleishman, 1970, p. 25)

As Table 1-1 illustrates, it is improbable that a generally acceptable taxonomy of performance will be developed in the near future. It is left to each interest group to generate its own taxonomy.

Just as the need of naturalists to communicate led Carlus Linnaeus to develop his *Systema Nuturae* in 1735, so it was the need of educators to communicate about educational objectives that motivated them to develop a classification system for education in 1948. Linnaeus' taxonomy was an extremely helpful tool for biologists to communicate accurately among themselves. His system of classifying living things into phyllum, class, family, genus, species and variety is familiar to anyone who has had science in the secondary school.

The committee of College and University Examiners was interested in devising an equivalent standard classification system which could serve as a basis for curriculum builders and test makers. Accordingly, the committee addressed itself to the cognitive and affective domains of the system, but set aside the development of psychomotor domain because they felt that there was not a need for it at that time.

One of the initial problems addressed by the committee was that of considering the alternatives of categorical classification in contrast with taxonomic classification. They chose taxonomic because taxonomies would be a more powerful tool for the long-term inquiry into the nature of educational phenomena. The structural rules for taxonomics does not allow arbitrary elements which are tolerated in the usual categorical classification system. Specifically, taxonomic rules require a hierarchical ordering of categories based upon some factor such as *complexity* while at the same time the categories correspond to some "real" order represented by the classification terms. Subsequently, the cognitive domain was arranged around six major classes, namely, 1) Knowledge, 2) Comprehension, 3) Application, 4) Analysis, 5) Synthesis, and 6) Evaluation. Each class characterized a more complex behavior than its predecessor and represents a logical order of acquisition. The committee also developed a parallel structure for the Affective Domain but with the five classes: 1) Receiving, 2) Responding, 3) Valuing, 4) Organization, and 5) Characterization by a value or value complex.

The Taxonomy of Educational Objectives: Handbook I: Cognitive Domain, edited by Bloom, was first published in 1956; and Handbook II: Affective Domain, edited by Krathwohl, appeared in 1964. The Classification of Educational Objectives, Psychomotor Domain, edited by Simpson, appeared in 1966. In contrast with Handbooks I and II, Simpson's work was supported by a grant from the U.S. Department of Health, Education, and Welfare, Office of Education. Her charge was "to develop a classification system for educational objectives, psychomotor domain, and if possible, in taxonomic form," (Simpson, 1966, p. 1).

In the next section Simpson's schema will be examined along with other proposals and systems.

PSYCHOMOTOR TAXONOMIC CLASSIFICATION SCHEMES

Schemes for Classifying Objectives

Simpson's Schema. Elizabeth Simpson's approach, in developing a taxonomy for classifying educational objectives in the psychomotor domain, was based on the action-pattern concept. That is to say, the levels in the classification schema follow the way a learner acquires a skill. Specifically, Simpson's taxonomy is as follows:

1.0 Perception — really parallel to receiving in the affective domain.
  1.10 Sensory.
    1.11 Auditory — hearing.
    1.12 Visual — seeing.
    1.13 Tactile — touching.
    1.14 Taste — tasting.
    1.15 Smell — detecting odors.
    1.16 Kinesthetic — a sense of feeling or of one's body in space.
  1.20 Cue Selection — differentiating proper cue as a guide.
  1.30 Translation — determining the meaning of a cue for action.
2.0 Set — readiness for action.
  2.1 Mental Set — knowledge necessary to enable action.
  2.2 Physical Set — focusing of attention and body position.
  2.3 Emotional Set — favorable attitude, i.e., willingness to respond.
3.0 Guided Response — overt act under supervision.
  3.1 Imitation — "copying" an observed performance of another.
  3.2 Trial and Error — multiple response learning — selecting the response which provides the desired results.
4.0 Mechanism — learner achieves some confidence and proficiency in the performance of the skill or act.
5.0 Complex Overt Response — learner performs smoothly and efficiently.
  5.1 Resolution of Uncertainty — learner proceeds with confidence.
6.0 Adaptation — learner alters acquired skill to meet new situational demands.
7.0 Origination — creating new psychomotor acts or ways of manipulating materials out of understandings, abilities, and skills developed earlier.

(NSMI, 1972, p. 50)

Hauenstein's Construct. Dean Hauenstein (1970) developed a classification system which is predicated upon a relationship between the categories in the cognitive and affective domains. He posits that "the relationship between the cognitive and affective functions produce a psychomotor vector . . . (which) varies according to the intersecting strengths of the cognitive and affective functions," (p. 27). The construct appears as follows:

> *Observation* — in watching a demonstration the learner is receiving (affective) and using recognition and recall (cognitive).
>
> *Imitation* — is in fact when the learner responds (affective) to the observed demonstration and infers learner comprehension and interpretation (cognitive).
>
> *Manipulating* — refers to actually applying (cognitive) those skills which have been observed and valued (affective).
>
> *Performing* — implies analysis and synthesis (cognitive) wherein the learner is able to organize (affective) his/her actions in applying a skill in a new situation.
>
> *Perfecting* — infers evaluation (cognitive) and characterization (affective) abilities (p. 27).

Hauenstein's position is not without some support for Simpson also points out the parallels between her perception and emotional set levels with the affective taxonomy's receiving and responding categories respectively. Although the construct represents a taxonomic sequence, it lacks the detail present in Simpson's schema. Instructors will certainly find Simpson's taxonomy the most discriminating of the two.

Hoover's Taxonomy. Kenneth Hoover, a well known writer on curriculum and instruction in secondary education, has prepared a psychomotor taxonomy not unlike Hauenstein's. In essence, Hoover's taxonomy is:

> *Observing* — learner watches a more experienced person perform.
>
> *Imitating* — learner conscious of deliberate effort to imitate model.
>
> *Practicing* — conscious effort no longer necessary, performance becomes habitual.
>
> *Adapting* — terminal level; perfecting of skill; greater perfection involves adapting minor details (Hoover, 1976, p. 26).

Similar to Hauenstein's construct, this taxonomy has only limited use in specifying educational objectives in the psychomotor domain.

Moore's Taxonomy of Perception. Noble, (1968) in his discussion about learning psychomotor skills, objects to the commonly used shorter term *motor skills* or *motor learning* and argues for *perception-motor* or *psychomotor* as preferred terms. Moore (1970) takes the position that reading, a perceptual-motor skill, is of prime importance in school and has proposed a carefully developed taxonomy of the perceptual domain based on works of Guilford and Witkin. Moore's proposed Taxonomy of the Perceptual Domain, in simplified form is as follows:

Sensation — awareness of stimuli, e.g., color, sound, odor, etc. Ability to detect changes in those stimuli.

Figure Perception — awareness of an entity in terms of size, shape, location, etc.; also relationship of parts to each other and the background.

Symbol Perception — awareness of denotative signs and ability to assign them to an appropriate class or category.

Perception of Meaning — awareness of the significance or value of a symbol and insight into the cause and effect relationships between symbols.

Perception of Performance — analytic or diagnostic abilities in problem solving (p. 384).

Moore (1970) says that her taxonomic scheme "works" particularly well for auditory perception tasks such as the measurement of auditory diagnostic ability in automechanics. Other applications of the taxonomy in industrial education appear in Baldwin's chapter on Evaluation of Learning in Industrial Education (Baldwin, 1971).

Baldwin's General Specifications Approach. While on the faculty of the University of Illinois, Thomas Baldwin developed a Table of General Specifications in Industrial Education which embraced modified forms of the cognitive and affective domain taxonomies. The table was designed to cover all possible types of objectives in industrial education. In topical outline form his scheme appears in Table 1-2.

Table 1-2

General Specifications for Objectives in Industrial Education

BEHAVIOR DOMAIN	LEVEL DESCRIPTOR	
Cognitive	A	Knowledge
	B	Understanding
	C	Applications of knowledge
	D	Application of understanding
Perceptual	E	Sensation
	F	Figure perception
	G	Symbol perception
	H	Perception of meaning
	I	Perception of performance
Psychomotor	J	Perception
	K	Set
	L	Guided response
	M	Mechanism
	N	Complex-response
Affective	O	Receiving
	P	Responding
	Q	Valuing
	R	Organizing
	S	Value complex

(Baldwin, 1971, p. 858)

In Bloom, et al., (1971), Baldwin provides an excellent description of many practical applications of his specifications table.

Classification of Physical Performance

Cratty's Typology of Motor Skill. Bryant Cratty is well known in physical education circles for his work in the teaching of motor skills typical of activities in physical education. In his book, *Teaching Motor Skills,* (Cratty, 1973) he attempts to classify motor skills according to their complexity as they are performed. His four-part hierarchical breakdown is presented here.

> *Simple Movements* — involve only one part of the body with the rest of the body acting as a stabilizer.
> *Compound Tasks* — simple components which are repetitive and involve timing of chained movements.
> *Complex Movements* — consists of two or more components which, taken separately, would be dissimilar in nature.
> *Skill Families* — a group of skills required to carry out a job such as a skilled drill press operator. (Cratty, 1973, p. 20).

Harrow's Taxonomy. Harrow (1972) developed her Taxonomy of the Psychomotor Domain along the lines of child growth and development theories. Consequently, her taxonomy reflects the stages in human growth. An adaptation of her taxonomy is as follows:

Reflex Movements — movements which are involuntary in nature.
Basic Fundamental Movements — patterns that occur during the first year of life.
A. Walking
B. Stretching and bending.
C. Manipulative movements
  — gripping
  — use of fingers
Perceptual Abilities — seeing, hearing, feeling, etc.
Physical Abilities — e.g., endurance, strength, agility, etc.
Skilled Movements — four levels in each category, e.g., beginner, intermediate, etc.
A. Simple adaptive skills
B. Compound adaptive skills
C. Complex adaptive skills
Non-discussive Communication — e.g., facial expression and "body language"

(Harrow, 1972, p. 96).

PERFORMANCE REQUIREMENTS APPROACHES

Abilities Requirements Approach

Fleishman in his research on psychomotor performance has "investigated more than 200 different tasks administered to thousands of subjects in interlocking studies" (Fleishman, 1972, p. 59). Through factor-analytical techniques he has been able to identify eleven psychomotor abilities and nine physical proficiency abilities which consistently appear as factors in psychomotor tasks. They are:

PSYCHOMOTOR ABILITIES

1. Control precision
2. Multilimb coordination
3. Response orientation
4. Reaction time
5. Speed of arm movement
6. Rate of control
7. Manual dexterity
8. Finger dexterity
9. Arm-hand steadiness
10. Wrist-finger speed
11. Aiming

PHYSICAL PROFICIENCY ABILITIES

1. Extent flexibility (twisting)
2. Dynamic flexibility (bending)
3. Explosive strength (throwing)
4. Static strength (gripping)
5. Dynamic strength (muscular endurance)
6. Trunk strength (trunk endurance)
7. Gross body coordination (jumping)
8. Gross body equilibrium (balancing)
9. Stamina (cardiovascular endurance)

(NSMI, 1972, p. 59)

Fleishman's abilities classification could be very useful for teachers working with the orthopedically impaired as well as other special needs learners. Shemick (1978) has proposed a system for individualizing psychomotor activities for the handicapped using Fleishman's factors as a basis for diagnosis and prescription.

Task Classification Approach. Paul Fitts (1965) suggested that motor tasks could be classified into four categories according to object and person motion. Merrill (1972) subsequently refined the scheme as follows:

> Type I Task — learner able to initiate activity when ready. Object of environment static and learner at rest. Example: chopping wood.

> Type II Task — learner static, but object or environment in motion. Example: worker stationed on a moving assembly line or hunter shooting a pheasant in flight.
>
> Type III Task — learner in motion and task object at rest. Example: newspaper carrier throwing newspaper at customer's front door while riding a bike.
>
> Type IV Task — learner in motion and task object in motion. Example: riveter catching red-hot rivets in a bucket on a structural steel project. (Merrill, 1972, p. 403).

In writing about analysis and specification of behavior for training, Miller (1965) laments "it is unfortunate that psychologists lack a behavioral taxonomy which is related to generalization characteristics of task performance" (p. 57). Since that writing, Fleishman and his associates in working toward a Taxonomy of Human Performance described four conceptual bases for defining a task, namely:

> *Behavior Description Approach* — categories of tasks are formulated on what operators actually do while performing the task (used for the *Dictionary of Occupational Titles*).
>
> *Behavior Requirements Approach* — emphasizes the cataloguing of behaviors that are *required* for successful performance (the experimental psychologist's approach).
>
> *Ability Requirements Approach* — derived through factor-analytic studies (exemplified in Fleishman's work).
>
> *Task Characteristics Approach* — treats the task as a set of conditions that elicit performance (exemplified in Merrill's object-person schemes).
>
> (Fleishman, 1975, p. 1130)

There continues to be a need for standardization of descriptive language in the research, for Fleishman (1970) reported that in his work on performance, 60 percent of all journal articles that he reviewed could not be used because the experimental tasks were not stated precisely enough (p. 41). Accordingly, in 1977, Shemick proposed a tentative taxonomy of psychomotor skill tasks which might be useful in psychomotor research in industrial arts.

A Tentative Skill Task Taxonomy. A view of the psychomotor research reveals that the wide range of findings reported is related to the differences in experimental tasks employed in the studies. In an effort to classify skill tasks in a developmental hierarchy, Shemick (1977) proposed a taxonomy of skill tasks. In partial and simplified form, the paradigm of that taxonomy appears in Figure 1-1.

GENERAL CLASS	TYPE OF SKILLED TASK	EXAMPLE
Developmental	Adaptive	Wood Carving
	Procedural	Assembling a piece of equipment
Reactive	Adjustive [continuous]	Steering a car or bicycle
	Response selection [serial]	Typing
Contiguous	Two hand coordination	Freehand lathe turning
	Two feet coordination	Operating accelerator & clutch of auto
	Hand & foot coordination	Foot pedal controlled sewing machine

[Shemick, 1977, p 51]

Figure 1-1. An abbreviated tentative skill task taxonomy

The purpose of the proposed taxonomy was to provide a meaningful frame of reference for developing performance objectives in curriculum work and/or serve as a working model for further skills differentiation study.

SUMMARY

While the interest of educators in a taxonomy of the psychomotor domain has been relatively recent, many psychologists have long been interested in different facets of the domain. Experimental psychologists are interested in how people acquire skills and study reaction time, transfer of training, etc. In contrast, differential psychologists study the correlation between traits, abilities and aptitudes in conjunction with skilled task requirements. Individual and environmental factors that influence psychomotor performance of skilled workers is the focus of scholars in emerging areas of industrial psychology such as ergomonics, human factors and biomechanics. As with educators who are concerned with psychomotor learning and performance, psychologists are also interested in a taxonomy of human performance. What has confounded efforts in the development of a generally acceptable system has been the differing information needs among potential users. Consequently, for the moment each group will have to develop a classification system that fits its particular needs. Accordingly, educators will find the educational objectives classification systems of Simpson and Baldwin of greater practical application than the proposals by Cratty and Harrow.

While the person-object scheme by Fitts and Merrill has limited application, the abilities classification proposed by Fleishman could be of considerable application to persons interested in the physical requirements of psychomotor tasks. Shemick's proposed Skilled Task Taxonomy could have value for researchers in industrial arts who are interested in replicating teaching strategies with comparable skilled tasks.

Hauenstein's concept of the psychomotor domain as being a vector between the cognitive and affective domains illustrates the fact that while the centers of domains are mutually exclusive the edges blend into each other like the color bands of a rainbow.

ORGANIZATION AND RATIONALE FOR THE FOLLOWING CHAPTERS

Chapter Two serves as a follow-up on this chapter's discussion on classification schemes in the psychomotor domain. Singer presents most of the contemporary theories and models for psychomotor learning. Chapter Three, by Paul Brauchle, is concerned with translating the models presented by Singer into the industrial arts/technology teacher educator's point of view. In Chapter Four, Keith Blankenbaker deals with the developmental and maturational aspects of psychomotor abilities. This chapter should be especially helpful to those in industrial arts who are concerned about teaching in the intermediate grade levels.

Chapter Five is focused on assessing psychomotor abilities and aptitudes of learners at all levels, especially as assessment contributes to career education and development. Tom Long provides an extensive description of the available assessment instruments. Chapter Six, which provides insights into evaluating psychomotor achievement, is by Richard Erickson who is recognized as having special expertise in evaluation in industrial education. Chapter Seven, by James DeCaro, offers carefully researched instructional strategies for teaching psychomotor activities.

Chapter Eight is coauthored by Noble and Vercruyssen, who are researchers in the area of human factors, which is the study of factors that influence psychomotor performance. They have done a comprehensive job of reviewing the literature. Harold PaDelford has provided the industrial arts view and response to this chapter. The final chapter, Chapter Nine, on future research objectives has been written by a nationally recognized scholar in motor behavior, Robert Christina. Lambert and Rose are his graduate researchers. Pete Martinez has responded to the predictions and trends identified in that chapter.

The interested reader and dedicated scholar are referred to the many references at the end of each chapter for more specific and detailed treatment of the discussed.

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Chapter 2

Contemporary Approaches to Theories and Models of Perceptual and Psychomotor Learning[1]

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The conceptual orientations described in this chapter are associated with approaches to describe and predict behavior different than the standard S-R and perceptually oriented theories. Although these new models and theories can be traced back twenty or so years, their prominence and impact on research, education, and skill learning has been recent. One can readily perceive unique terminology, methodology, and intent of application, as well as some resemblance to the standard and well-known theories.

In recent years, we have witnessed the formulation of models and theories that are specific to motor skill acquisition. These developments are exciting to those interested in motor skills, for they indicate that serious scholarly thought is being given to the skills area. Some developments are highly theoretical. Others appear to be quite practical and applied. The ones described here are not necessarily unique from each other or independent of previous efforts in theory and model construction. They do, however, reflect the latest thinking in regard to skill acquisition.

For convenience, these models are characterized in the following manner:

1. General descriptive: emphasis on general characteristics of skilled performance, usually for practical consideration.

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2. Information processing: emphasis on perception, decision-making, capacity to handle information, and information-retrieval capabilities.
3. Cybernetics: emphasis on personal control through self-regulating mechanisms.
4. Adaptive or hierarchical control: emphasis on higher-order and lower-order routines and person-computer analogies for the organization of information and control of behavior.

The concepts and terminologies in these approaches tend to represent technological advancements. The models evolved out of similar histories and are very much interrelated, as A. W. Smith (1974) indicates. Many ideas applied in technology have also been applied to human behavior. For example, cybernetic models were advanced to explain the way in which a person exhibits control in behavior and makes behavioral changes. Information processing models have tended to describe the capabilities and limitations of an individual's perceptual, memorial, retrieval, and decision-making abilities. Both of these kinds of models, along with adaptive ones, are extremely popular today, especially in the skills area, where they appear to be more relevant in describing movement-oriented behaviors than do association and older versions of cognitive-perceptual theories.

The key concepts of these three models, as related to personal control over behavior, are presented in Table 2-1. Although it is possible to focus on cybernetic, adaptive, and information-processing models independently, the understanding of complex motor behavior requires the integration of these three types of approaches. As a result, it is easier to deal with more concepts and events associated with skill learning.

TABLE 2-1
The Human Behaving System: Information-Processing, Cybernetic, and Adaptive (Hierarchial Control) Considerations

Variable	Information Processing	Cybernetic	Adaptive
Control systems	Sense registers, perceptual mechanisms, short-term memory store (limited capacity), long-term memory store (unlimited capacity), information transformation, evaluation, storage usage	Response-produced feedback, ongoing performance regulation, modification, and adaption, (closed-loop (peripheral control)	Programs, plans, schemes, higher-order and lower-order routines (hierarchical regulation of behavior), conscious and subconscious behavior, open loop (central control)

As a final introductory note, there is great excitement today in a branch of psychology called cognitive psychology. Cognitive processes are studied as they influence the processing of information that leads to effective behaviors (e.g., Posner, 1973). The main view is that the person is an active processor of information rather than a passive receiver of responses that are stamped in through practice (Ellis, 1978). Cognitive psychologists have tended to advance information-processing models, to contrast with the older associationistic models.

The person does not totally influence any situation; nor is it probable that the reverse occurs. Whereas behaviorists might lead us to view human behavior as passively controlled by situational dictates, cognitive psychologists suggest that we actively control our environments. The truth probably lies somewhere in the middle. Behaviors are not produced without cues or stimuli. Behaviors are directed in response to stimuli. But all people do not respond similarly to the same events, thereby demonstrating a pseudoprinciple of self-determination. In a sense, then, associationistic behaviors are indeed developed, but in a person's own way. Let us examine in more detail the salient features of the models indicated in Table 2-1.

GENERAL DESCRIPTIVE MODELS

A number of models of skilled acquisition seem generally to describe involved processes, without leaning to cybernetic, associative, information-processing, or adaptive camps. Sometimes the approach is toward a specific aspect of performance, such as the ability to transfer previous experiences to present demands, or the quality of skills retention. An interesting model, leading to much research on the ability of subjects to perform generally well in a number of tasks, versus specifically in task performance, was developed by Franklin Henry (1960). The value of this model is its fruitfulness in encouraging research efforts, especially in the relationship of reaction-time and movement-time performance in various laboratory tasks.

Bryant Cratty's 1966 model is a three-level approach at suggesting the organization categories of variables that influence learning and performance. He suggests that general human abilities and characteristics as well as task-specific factors be considered as determiners of level of achievement. The Fitts-Posner model of skill acquisition indicates three stages of development in the learning process, going from learner helplessness and dependence on many sources of information to independence and self-controlling operations. It is particularly appealing as a general descriptive overview of the nature of the acquisition of skill, from initial performance level to the most proficient. Ann Gentile's flow model of the mechanisms involved in the early learning of skills is derived from research and theory, with special direct applications to instruction. It is especially useful for teachers involved in instructing students how to learn skills.

In many respects, the models presented here and throughout this chapter are quite complementary. In other words, similar operational mechanisms and processes are indicated within the models, although at times different terminologies are employed by the proposers. Emphasis also differs. We should expect similarities among the models when they are reduced to their simplest forms to describe similar aspects of behavior. On occasion, however, data may be interpreted in a variety of ways for the purpose of model construction; incomplete data will lead to alternative hypotheses.

The Fitts-Posner Model

Paul Fitts and Michael Posner (1967) have described skill learning as occurring in three phases. Although described in a general way, there is intuitive acceptance of these phases, with evident implications for more effective instructional techniques and an understanding of the learning process. The three phases are:

Phase I: Early, or cognitive.
Phase II: Intermediate, or associative
Phase III: Final, or autonomous.

In the earliest stage of skill learning, the cognitive, the individual is burdened to understand directions, to attach verbal labels to movement responses. The thought processes are extremely active: What is the learner to do? How? The learner attends to the variety of cues that surround the situation and attempts to reduce the number that are useful. Written directions, verbal instructions, and/or live models might be provided, and this information must be translated into personally effective movements.

In the intermediate or associative stage, primary concern is for practice conditions and requirements. Which kind of training schedules should be followed? Should practice be continual or spaced with rests? Should the emphasis be on speed, on accuracy, or both in the execution of movements? Should whole or partial methods of practice be followed? The learner understands what is supposed to be done and now the concern is for those practice conditions that will most efficiently and effectively lead to proficiency.

The third and final stage, according to Fitts and Posner, would be the autonomous stage. The highest level of skill is demonstrated with a minimal amount of conscious involvement. Acts performed in this stage are almost impervious to distractions and stress. The soccer player dribbles the ball without attention to this activity; instead, thought is directed ahead to the impending situation: where to go, whether and when to pass or kick to the goal. The gymnast executes routines with little apparent attention to the specific details of the movements. In addition, it should be pointed out that inappropriate aspects of performance are very difficult to correct when they have been well-learned.

Thus, the learner progresses from an extremely conscious role in the activity, where verbalization and understanding are crucial and where, of course, the movements are quite crude and probably inappropriate on many occasions, through an intermediate phase, in which the emphasis is on practice conditions. The learner then goes on to an autonomous stage, where execution occurs with a minimal amount of conscious involvement.

Gentile's Model

In one of the few attempts to apply a skill acquisition model directly to teaching, Ann M. Gentile (1972) has delicately balanced a concern for neurophysiological and psychological experimental data, behavioral concepts, and the relatively naive teacher of skills. This model is presented in Figure 2-1. It indicates the factors involved in the initial stage of skill acquisition, and the illustration is clear enough so that further discussion of it is probably not necessary. The model is of special value to teachers of skills, as they can incorporate the basic concepts in their teaching.

Gentile differentiates closed and open skills and suggests alternate teacher strategies for dealing with them. Two stages of skill development are suggested: (1) general ideas of the act and (2) fixation and diversification. Stage 1 would involve accomplishing a goal with a general movement pattern; stage 2 is associated with a particular

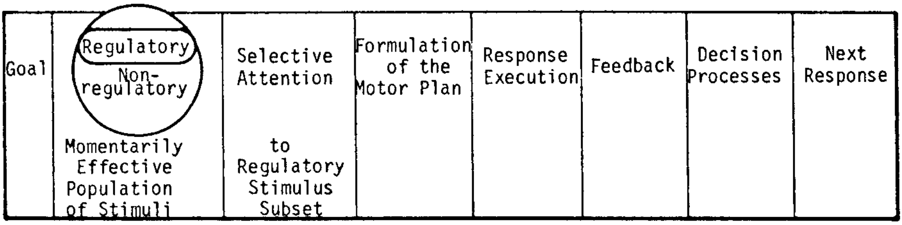


Figure 2-1. Initial stage of skill acquisition (from Gentile, A. M. A working model of skill acquisition with application to teaching. *Quest*, 1972, 3-23). Reprinted by permission.

level of skill. The demonstration of excellence in closed skills suggests a fixation process; that is, the movement patterns become refined and stable. For open skills, a diversification of patterns must be mastered because situational cues vary easily and often unpredictably. The contrast of open and closed skills, in terms of their characteristics and appropriate learning strategies, represents a major contribution of Gentile's work. The notion of how decision processes may work and how teachers may facilitate them also represents a significant contribution.

INFORMATION PROCESSING (COMMUNICATION) MODELS

Traditionally, information-processing models tend to provide the framework for examining limitations of attention, perceptions, memory, and decision-making in the performance of skills (see, for instance, Posner, 1966). The proficient execution of simple or complex movement behaviors depends greatly on the organism's capacity for discriminating effectively among a variety of cues. The capacity of the learner to deal with a number of cues, to transmit information at a fast rate, and to retrieve derived information from memory is of interest to information-processing theorists.

An understanding of one's capacity to attend to a number of stimuli simultaneously leads to applications that might be made for useful instructional techniques. This is also the case when we learn about limitations in one's capacity to register and code information in storage, as well as to retrieve it at the right time — although appropriate organizational processes will help make best use of this capacity. The ability to anticipate events is an outstanding feature of the skilled performer, who responds to the fewest possible cues. The system is thereby freed to think ahead and anticipate circumstances while it executes acts, as if in a programmed state. Attempts made by information-processing theorists have been the most fruitful in describing internal organizational variables of influence on skilled performance. Actually, many information-processing models are cybernetic as well, because self-control and regulation systems are considered. Often there is great difficulty in describing a model as strictly cybernetic or information-processing, for these approaches to understanding and explaining skill learning overlap considerably.

Information theory, also called *communication theory* in its original form, is an example of probability theory serving as a basis for a model. C. E. Shannon and W. Weaver are credited with its development in 1948; their publication (1962) describes the formulation of the theory and contributions to it. This descriptive and quantitative theory has been used mainly for verbal learning, with visual displays, and tracking, but it is inviting to speculate on its application to gross motor skills, as Harry Kay did in 1957.

The capacity to transmit information is determined by assigning numbers to various magnitudes of stimuli. *Uncertainty* and *information* are terms used interchangeably, for the more uncertainty in a situation, the greater information can be of assistance. In other words, information removes or reduces uncertainty. George Miller (1956) compares variance to amount of information, because greater variance indicates more uncertainty. In any communication system, person, or machine, there is a great deal of variability in what goes in and what comes out. Naturally, a good system will show some relation between input and output. The amount of overlap between input and output, whether expressed as variance or amount of information, is illustrated in Figure 2-2. In this case, the relationship between input and output would not be great. Performance output would not be of a high caliber, as there is only a small area of overlap between A and B (variance in common).

The binary digit (two possibilities — yes or no), a bit, is the unit used in the measurement of information and uncertainty. The object, then, is to determine the number of bits (the power to which 2 must be raised to equal the number of alternatives) needed to solve a particular problem. Fred Attneave (1959) presented the simple illustrative case where, of sixty-four square cells in a large square, the learner must guess the predesignated cell. With the formula $M = 2^H$, where M = the number of alternatives and H = binary possibilities, we substitute $64 = 2^6$ for example. Six questions, or six bits, are needed to find the cell in question. The questions might be: (1) Is the cell in the right thirty-two cells? Yes. (2) Is it in the upper half? No. (3) Is it in the lower half? Yes. In this line of questioning, the correct cell could be discovered in six statements. One bit of information is needed to make a decision between two alternatives, two between four alternatives, four between sixteen alternatives, and six bits for sixty-four alternatives.

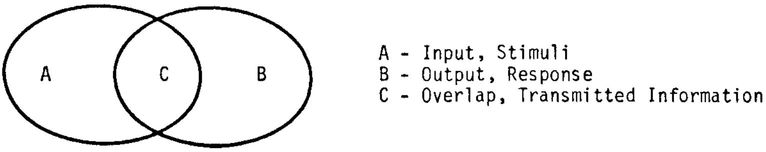


Figure 2-2. The relationship of output to input.

Figure 2-3. Information processing.

We often talk about the uncertainty in stimuli (termed information in information theory) and responses. How much can we remember in a given situation; how many objects or words can be recalled after a short exposure to them? Information transmission is another way of talking about accuracy and Figure 2-3 serves to represent the information-processing system in simplified form. The sensory processes begin the encoding process; information is then processed further and transmitted in the organism, decoded, and translated into muscle movements that reflect purposeful behavior. No mechanism, machine, or person is perfect; noise (amount of interference or uncertainty) may be present anywhere in the system — in the encoding and decoding or transmission mechanisms — that is, anywhere processing takes place. Therefore, it is a rarity when the response is exactly appropriate in complex motor behavior.

Every person has a *channel capacity* above which information cannot be transmitted. This capacity can be determined by increasing the input and measuring it with the responses, for if the material can be handled accurately, there will be few errors. With too much of an increase, more errors are expected. Greater input results in increased output, to a point, as there is an asymptotic value for every channel. For example, it is not difficult to distinguish among a few tones. When more tones are presented to the observer, a limited number of them will be recognized and distinguished. This number can be increased, however, with the use of better organizational strategies. This is one way in which individuals differ.

It has been found that 2.5 bits is the average channel capacity of the typical listener making judgments in pitch. This number of bits is equal to about six alternatives. In other words, if an infinite number of alternate pitches is presented, the average listener can only distinguish about six of them. Other studies indicate that for unidimensional judgments, for individual sensory attributes, 6.5 bits is average. More dimensions increase the total channel capacity but decrease accuracy for any particular variable. In this case, the person makes rough judgments.

It has been shown that an individual can increase the amount of information stored. When the object is to memorize a series of numbers, more can be remembered if these numbers are recoded. If the channel capacity of the learner of motor activities could be determined, the appropriate amount of information could be provided at one time. Presenting too much material at one time would overload the learner and not be monitored, too little would not promote maximum use of the time allotted. The search for the number of bits that could be transferred in a motor learning situation certainly is worthwhile.

One of the most valuable contributions of information theory has been the analysis of processes associated with selection, perception, memory, and decision-making in skilled performance. Previously in theory and research, emphasis had been on the observation of the response alone. It is recommended that the reader examine Kay's (1957) article to understand better the relationship between information theory and skilled performance.

One of the more interesting phenomena called to our attention by information-processing theorists concerns storage and retrieval processes related to information. While learning written material, knowing how to "chunk" information is extremely important. That is, if we have to learn a serial listing of fifteen different numbers, progress would be slow indeed if we took one number at a time. By chunking them — that is, grouping them perhaps in two's or three's — learning, memory, and retrieval are vastly improved. We can only process so much material at one time. But we can improve on the efficiency of the system. Instead of fifteen separate numbers to learn, chunking (a coding system) in groups of three results in five "numbers" to be acquired. Let us say that the list was as follows:

1 8 2 9 0 4 6 3 8 7 1 9 5 9 2

Try to memorize the list with each number in correct order, one by one. Now try chunking.

182 904 638 719 592

Easier? It should be. The point is that we can improve on our learning when we know how to organize stimuli in a meaningful and more simplified way. Chunking and making associations help.

Welford's Model

For many years, one of the most impressive scholars in the area of skilled performance has been A. T. Welford. He has researched the mechanisms that operate between sensory input and motor output, primarily using relatively simple laboratory tasks that involve reaction time or the tracking of moving targets. His concept of these mechanisms as composing a "communication channel of limited capacity" indicates a desire to determine which mechanisms function, how, and with what restrictions during human performance.

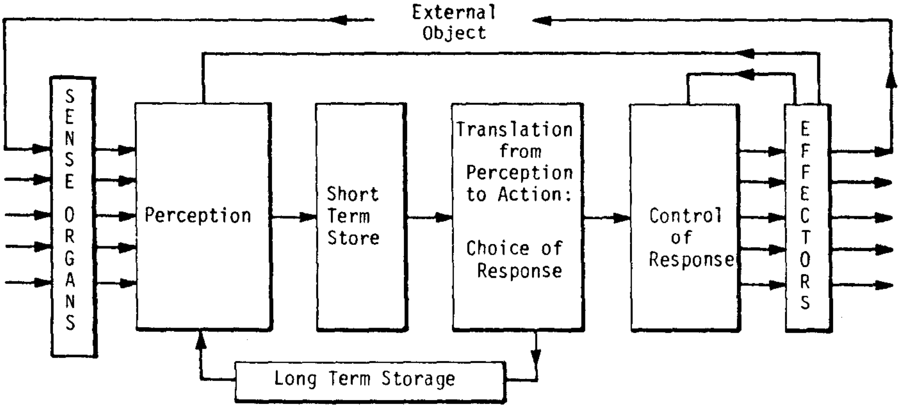


Figure 2-4. Hypothetical block diagram of the human sensorimotor system. Only a few of the many feedback loops that exist are shown. (From Welford, A. T., *Fundamentals of Skill*. London: Methuen & Co., Ltd., 1968). Reprinted with permission.

Motor performance for Welford is illustrated in Figure 2-4. Of interest is how information is perceived and translated into action, with special reference to short- and long-term storage systems in response control. He advocates (1) quantifiable behavioral theories and improved psychometric techniques, (2) person-machine comparisons to study similar operations, (3) close ties between neurophysiology and psychology in the study of mechanisms, and (4) the study of the components of complex behaviors within the appropriate broad and natural context.

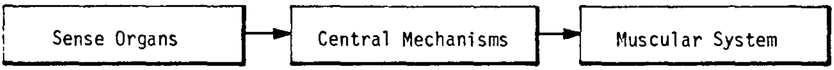
Mathematical formulas and logic, along with extensive data, have enabled Welford to propose "laws" about a person's channel capacities. One of the most famous of his proposals is the single-channel operation of the human organism. An examination of an individual's ability to process information presented simultaneously and to perform on dual tasks led Welford to postulate limitations in the channel capacity to attend to cues, process information, and respond effectively in a number of ongoing acts. Welford has also suggested a formula for predicting speed of arm movement as reflected by the nature and distance of the target and other variables. Space does not permit a summary of all of Welford's contributions to theory and research, but the reader might very well want to examine Welford's major and comprehensive book, *Fundamentals of Skill* (1968).

Limitations in processing information are provided in the following example. The single-channel hypothesis predicts that the central mechanisms can handle only one signal or set of signals at one time. If a second signal occurs right after a first signal, response to the second one takes longer, as it has to wait until the central mechanisms are free (Welford, 1976). Welford theorizes that movement time is determined more by central processes controlling movement than by the factors of muscular effort involved. Choice reaction time is primarily affected by the translation mechanism. Performance is limited by the phasing and coordinating movement of the central mechanisms.

In the writings of Welford and other scholars concerned with skill acquisition and motor performance, there tends to be agreement on the fact that the learner responds to both external, or situational, demands and internal (self-controlling and regulating) mechanisms that operate as response-produced stimuli. An understanding of how a person processes situational or response-produced information, with what capabilities and rapidity, suggests instructional techniques that would be favorable to the learner. Redundant information or too much information could be a waste of time or overtax the channel capacity. Too little information might result in inadequate cues and poor performance. It also might indicate that the channel capacity is not being used to its fullest advantages.

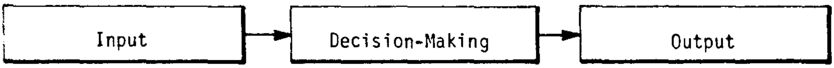
Whiting's Model

One of the more popular models developed in recent years is attributed to H.T.A. Whiting (1969, 1972). His work is an excellent example of how a relatively simple systematic model can lead to greater perceptivity of the relationships of subsystems associated with motor performance. Structural components, functional components, central mechanisms, and a composite are shown in Figure 2-5. The composite model reflects not only the general processes all persons use in performance, but also the effects of individual differences in body capabilities and in environmental influences. As we have seen thus far, very few models have taken into account individual differences and their effects on performance. The same is true for the effects of various practice conditions and environmental situations on learning and performance. Although Whiting is primarily interested in the similar mechanisms by which individuals acquire skill, at least his model reflects factors influencing differential outcomes in human performance. But primarily, his model falls into the information-processing category. The emphasis of Whiting's work has been directed to the neurophysiology and psychology of the central mechanisms involved in performance, on such factors as selective attention, arousal, and decision-making.



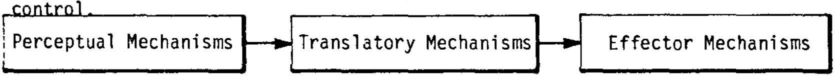
Physical Components

which at a functional level are responsible for input to the system decision-making and output.



Functional Components

At a more complex level of analysis, the central mechanisms may be considered to carry out three major functions: perception, translation, and effector control.



Central Mechanisms

These three subanalyses can be incorporated into a composite model:

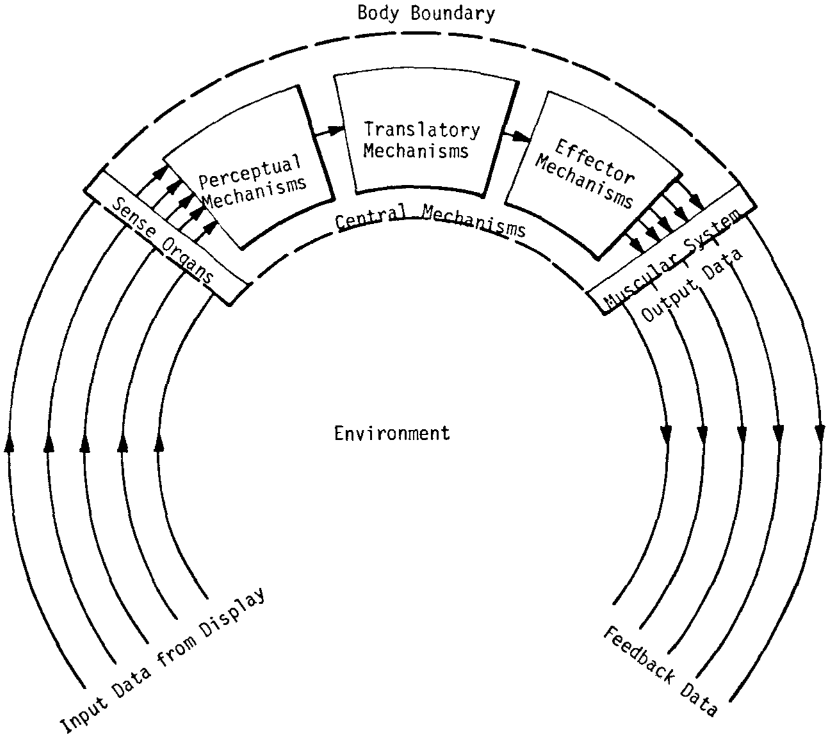


Figure 2-5. Systems analysis of perceptual motor performance. (From Whiting, H. T. A. Overview of the skill learning process. *Research Quarterly*, 1972, *43*, 266-294). Reprinted with permission of American Alliance for Health, Physical Education, Recreation and Dance publisher.

CYBERNETIC [CONTROL] MODELS

Cybernetics deal with control and communication. In the cybernetic viewpoint, biological evidence is considered in terms of mathematical precision; cybernetics cuts across many disciplines, namely, biology, psychology, communication, engineering, mathematics, and physiology. Actually, the origin of the word *cybernetics* is Greek; it is based on *kybernetes*, meaning "steersman; one who operates a ship and has to keep it on course." The human brain and machine computer are both types of control systems — hence, the descriptive terms to describe and compare them.

An analogy to describe cybernetics exists between a human organism and emitted behavior and an electronic transmission system and transmitted events. The digital computer contains an input and output system, a control, and a storage system. The human organism receives situational cues and responds, has a brain as a controlling process, has a storage system in the form of memory, and receives response-produced feedback, which helps to regulate subsequent actions. Cybernetics explains human behavior as a flexible internal model where actions are dependent on flexibility and the adaptability of the response. Consequently, responses will be adjusted according to the availability and utilization of feedback.

The idea that a person and a machine might be compared on the basis of their activities and means of functioning is by no means new. However, it took the work of Norbert Wiener in 1948 to crystallize the relationship and formulate *cybernetics*. Formally defined, cybernetics is the study of control processes and mechanisms in machines and human organisms. The theory in its original presentation as well as developments in this area was presented by Wiener (1961).

The most important concept in cybernetics is *feedback*. It occurs when some of the output from the system is isolated and fed back into it as input. The potential to use feedback is available to humans as well as closed-loop control machine systems. Another name for the feedback system is a *servosystem*. A servosystem is a closed-loop control system utilizing the principle of feedback. Information, on progress or position, is sent back to the device that controls the output; the input is then modified, and the output is corrected. Every human organism must have information about or see the results of actions, otherwise improvement will not occur. In a skilled act, responses cause input from the proprioceptors*, eyes, and other sense organs to be sent back to the system, and this feedback is informative to the person. When

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*complex sensory receptors located in muscles, tendons, joints, and the inner ear.

errors in movement are made, feedback informs us about the nature and extent of the correction needed. In other words, performance output is constantly modified through the use of information feedback when it shows a discrepancy with the input information. Many motor skills can be thought of as continuous closed-loop system interactions between performance and the sensory effects of each performance. Continual activity is controlled and regulated by means of this sensory input.

Learning situations, writes K. U. Smith (1968), are dependent on space-time patterns of motions. Basic body movements are space structured, and learning is a process of establishing new spatial relationships in patterns of motion. The human organism is not a "victim" of the environment, responding passively to environmental stimuli, but rather dynamically, with the resultant activity processed in the form of feedback for control and guidance. Smith, with his interest in realistic learning problems and a concern for motor patterns and skills learned outside the laboratory, has demonstrated but another of the recent attempts to move away from an S-R viewpoint of learning, which he calls artificial and restricting, to our acquisition of knowledge on the learning process.

Adaptive behavior is modified through experience. George (1965) suggests that feedback brings about simple adaptation, whereas complete adaptation is the outcome of learning. The typical example of a device that operates on the principle of feedback is the thermostat. This is a self-controlling, self-regulating device, for temperature itself controls the change of temperature. When the temperature is low, the thermostat turns on the heating unit, causing the temperature to rise. When the temperature reaches the desired level, the thermostat turns off the unit, the temperature will eventually fall, and the process will be reversed. Room temperature is the input, furnace activity the output, and the difference between the thermostat and the room temperature is fed back into the system as input.

In cybernetics, the descriptive phrase often used is closed-loop systems. That is, certain types of apparatus and apparently many kinds of human behavior appear to be self-regulating. Adjustments are made according to the detection of discrepancies within the system. The primary mechanism is feedback, which encourages and permits detection and correction. Feedback, in this type of theory, refers to the sensory aftereffects of responding. This information is then used by the learner to make adjustments in behavior until the goal and behavior are matched.

By contrast, an open-loop system does not make adjustments, as no error regulator or feedback mechanism is postulated. Typically, association (S-R) theories might be thought of as open-loop systems. The orientation is to external control over the learner, that adjustments made in the environment can influence the learner's actions. Such researchers as K. U. Smith and Jack Adams have attacked association theories as not describing motor behaviors as adequately or appropriately as closed-loop models. Smith has written extensively for many years in this area and has undertaken much research to support his notions about cybernetic theory (Smith, 1972). A theory that has produced a considerable amount of attention recently is Jack Adams' closed-loop theory of motor learning, to be discussed shortly.

Bernstein's Model

From a perspective different from many of those reported in the literature, N. Bernstein, the late renowned Russian physiologist, contributed many cybernetic and biomechanical notions about coordinated and skilled activity. A number of his prominent papers have been translated into English (Bernstein, 1967), although of special consideration here is the one entitled "Some Emergent Problems of the Regulation of Motor Acts." As in any cybernetic model, the emphasis in this one is on the role of feedback for control and self-regulation. Differences are apparent as well, however, for Bernstein incorporates a heavy emphasis on physiology. A main point of Bernstein's is that the performer's changing and adaptive movements cannot be described only by efferent* impulses. The prominent role of afferent** feedback (stimuli produced from responses) was recognized by Bernstein for controlled movement in his closed-loop model.

Those of us who deal with skilled movements are obviously concerned with the integration of movement of the parts of the body involved. We have an enormous number of *degrees of freedom* (Bernstein's term) that we must control in successfully completing activities. There is great internal flexibility and elasticity. The more degrees of freedom one has in an activity, the more complicated the system and greater the difficulty in controlling it. Thus, to Bernstein, coordination in movement "is the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system" (p. 127). It is the organization of control. Which mechanisms are involved and how in this process? Let us examine Figure 2-6.

This diagram is typical in cybernetic theory in that it reveals a closed-loop interaction among the mechanisms to describe coordinated movement. It is unusual in some respects in regard to terminology and the conceptual relationship and the framework presented. The acquisition of skill suggests the stabilization of movements. Bernstein uses the term *motor structure of movements* to mean style in the execution of a skill. According to him,

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*Efferent — nerve impulses from the brain to the muscle.

**Afferent — nerve impulses from the receptor to the brain.

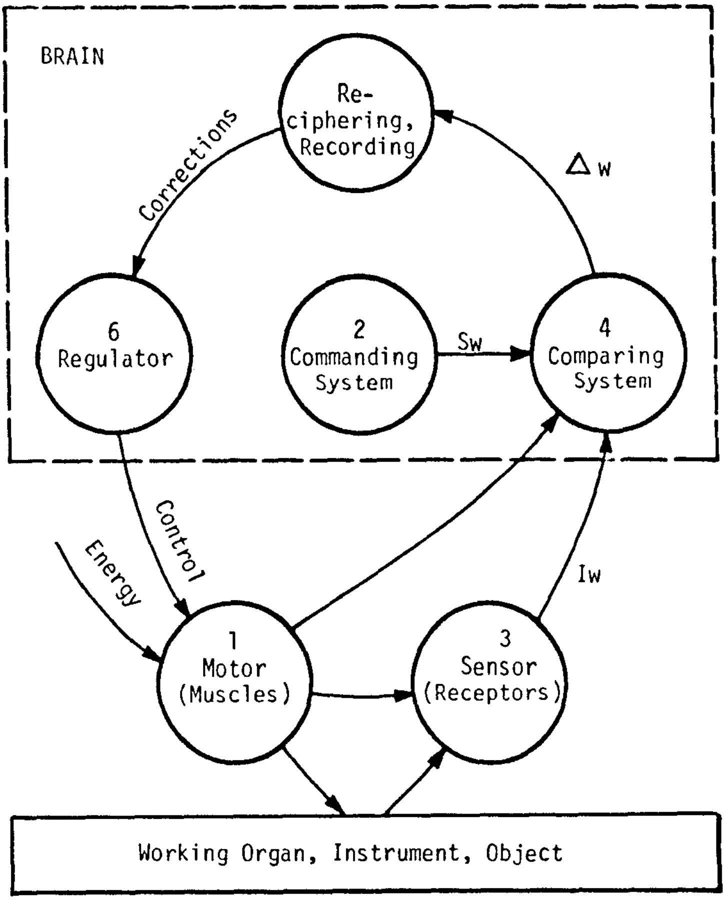


Figure 2-6. The simplest possible block diagram of an apparatus for the control of movements. 1] effector [motor] activity, which is to be regulated along the given parameter, 2] A control element, which conveys to the system in one way or another the required value of the parameter which is to be regulated, 3] a receptor which perceives the factual course of the parameter and signals it by some means to, 4] a comparator device, which perceives the discrepancy between the factual and required values with its magnitude and sign, 5] an apparatus which encodes the data provided by the comparator device into correctional impulses which are transmitted by feedback linkages to, 6] a regulator which controls the function of the effector along the given parameter [from Bernstein, N. The coordination and regulation of movements. Oxford: Pergamon, 1967]. Reprinted with permission of Pergamon Press Ltd.

> the process of practice toward the achievement of new motor habits essentially consists in the gradual success of a search for optimal motor solutions to the appropriate problems. Because of this, practice, when properly undertaken, does not consist in repeating the *means of solution* of a motor problem time after time, but in the *process of solving* this problem again and again by techniques which we changed and perfected from repetition to repetition. It is already apparent here that, in many cases, practice is a particular type of repetition without repetition and that motor repetition, if this position is ignored, is merely mechanical repetition by rote, a method which has been discredited in pedagogy for some time (p. 134).

Interesting comments for sure! Through practice we learn how to solve problems. Bernstein emphasizes the intellectual involvement of the individual achieving skill, not only the response itself. These and other explanations of movements are to be found in his writings.

Adams' Closed-Loop Theory

J. A. Adams' notions of closed-loop theory were first presented in an article in the *Psychological Bulletin* (1968) and then in the *Journal of Motor Behavior* (1971). Perhaps the basic difference between closed-loop and open-loop theory is, in the words of Adams (1968), that the latter holds that:

> proprioception is stimuli which can be the cues to which relatively long sequences of motor responses can be learned, and by secondary reinforcers. Closed-loop theory would say that proprioceptive stimuli can guide well learned responses because current proprioceptive stimuli from our movements are compared against their reference levels from past learning and are recognized as correct (p. 499).

Adams' conceptualization is oriented toward an explanation of simple, self-paced, graded movements. An example would be learning to draw a line of specified dimensions. Due to inadequacies in S-R theory, Adams has suggested that his theory offers an alternative approach to explain many of the fundamental variables and various mechanisms not touched on previously. He has proposed a reference mechanism, a *perceptual trace*, as central to closed-loop theory. Previously executed movements presumably leave a trace, or image, and are used by the learner to modify subsequent actions. Knowledge of results (KR) of the movement is compared to the trace. The sense of the movement (proprioception) is a major contributor to knowledge of results, and in turn to the perceptual trace. Other types of sense receptors, such as tactile and visual, are sources also. According to Adams, the perceptual trace is based on response-produced feedback-stimuli.

Early in learning, knowledge of results provided from someone else is extremely important, as the learner continually must adjust the trace accordingly. This stage has been termed the verbal-motor stage. The final stage, where skill is demonstrated at the highest levels, is referred to as the motor stage. When appropriate responses are continually made, knowledge of results reveals very little discrepancy with the perceptual trace. Essentially, knowledge of results is ignored and the perceptual trace is strong. In principle, the description is likened to volitional or willed behavior that ultimately becomes automatic.

Whereas a perceptual trace serves as the comparison base for knowledge of results, especially in early learning, a *memory trace* is posited as the selector and initiator of a response. Although both fast and slow movements are initiated by a memory trace, the perceptual trace and KR are used in different ways. In a fast movement, the response is over before KR can be used effectively during its execution. The KR match with the perceptual trace occurs after the movement and is valuable for the adjustment in the next response, if an adjustment is appropriate. During slow, continuous movements and in the verbal-motor stage, trace matches occur frequently and assist in correcting performance for its duration.

Many aspects of knowledge of results — e.g., delays and removals — are discussed by Adams. Presumably, without KR in the beginning stages of skill acquisition, the perceptual trace, which is weak, undergoes forgetting. As was mentioned previously, with high task proficiency, additional learning occurs without KR and is based on internal information. To summarize, the most unique concepts in the closed-loop theory are:

1. The identification of two traces in motor learning: the memory trace and the perceptual trace.
2. The heavy reliance on peripheral rather than central feedback mechanisms, where a person's performance output is compared against a reference model for the detection of errors.
3. The association of error correction with the selection of a new memory trace that yields a response to match the perceptual trace.

ADAPTIVE [HIERARCHICAL CONTROL] MODELS

Behavior can be viewed in terms of activities and subactivities. Certain enabling tasks must be mastered before higher-ordered ones can be displayed. The identification of all the activities, in sequential order, that must be performed if the goal is to be realized is an aspect of sound instructional procedures. Similarly, skilled behavior can be explored through the identification of higher- and lower-order operational processes. It is important to know how these processes, or routines, exist in relation to each other and at different levels of skilled mastery.

Assume that a person, like a computer, functions with higher-order (executive) programs or routines and subroutines or subprograms. It would appear logical that executive routines function with higher-order subroutines, at early levels of learning. However, they "delegate" their authority to lower-order routines in later skill development, thus freeing the system to attend to other matters. As an example, the boy learning to play basketball for the first time concentrates very hard on dribbling the ball. There is little choice or chance for him to do anything else. Yet, once the skill has been mastered, he apparently dribbles with very little conscious control over his activity and attends to such matters as previewing the game situation, thinking ahead about alternatives, and making decisions. The executive routines of control for dribbling have been freed, and other movements are operative. The executive program can be broadened — that is, expanded to encompass a higher-order goal.

An executive program contains subroutines that often operate in sequential fashion. Many skills involve sequential activities that, when properly timed, indicate optimal performance. In other words, the executive program, or master plan, contains the necessary subroutines when the act is well-learned. In order for the executive program associated with serving the tennis ball with a twist to the opponent's backhand and rushing to the net to be operational, subroutines (parts of the executor) must already be mastered. Figure 2-7 presents a superficial and partial example of this discussion.

The subroutines can be observed as foundational building blocks, mastery at each level helping to ensure goal realization. They can also be viewed in sequential format, with each one, from initial to terminal, contributing to the overall quality of the execution. The hierarchical concept of control over movement with increased skill helps to explain why certain acts, such as walking, appear to be automatic. There is little need for conscious control over routinized and well-learned responses. The *executor program* can be thought of as the *plan, idea,* or *goal* in a situation. The *subroutines* are the *processes* — e.g., movements, that enable the plan to be executed.

Also associated with the concept of the hierarchical development of control and organization is the notion of open-loop control. Movements become smoother when not under the constant monitoring of peripheral sensory feedback. Open-loop control means that a movement must run its course, once initialed, for approximately 200 to 400 milliseconds (Schmidt, 1975). A new program cannot be initiated by

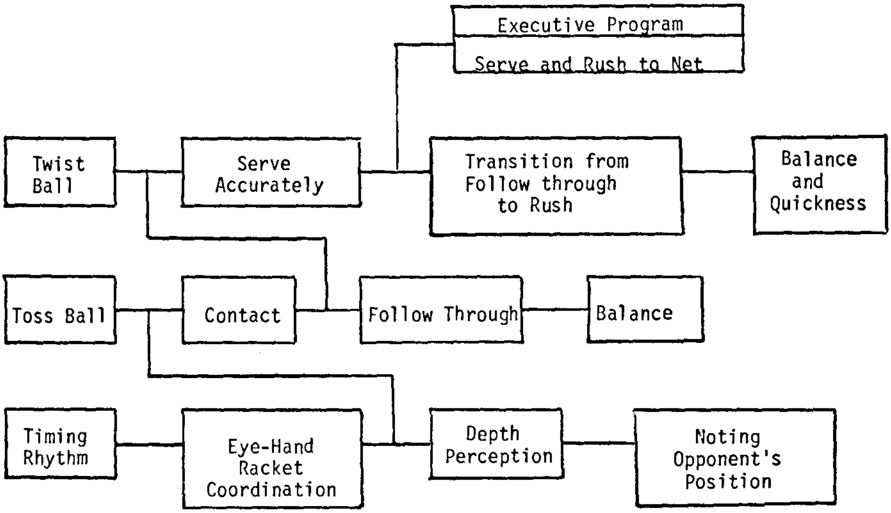


Figure 2-7. The relationship of subroutines to the executive plan of serving the tennis ball with a twist and rushing to the net.

a peripheral cue during this time. As we will see, this is a major argument posed by Schmidt and Keele against Adam's closed-loop concept of ongoing peripheral control during movement.

Some scholars have gone beyond the descriptive terminology of human-computer comparisons and have attempted to demonstrate the hierarchical functional organization of the nervous system. Jacques Paillard (1960), for instance, talks in terms of two levels of nervous system structures as he analyzes skilled movements: the lower motor-neuron keyboard and the upper motor-neuron keyboard.

Skilled movement patterns depend on the role of the corticomotorneural tracts in conveying messages, according to Paillard. The lower motor-neuron keyboard consists of the medulla and spinal cord and directly controls peripheral activity. The upper motor-neuron keyboard is associated with critical involvement and represents highest-level control. The activities within and between these keyboards are integrated in a manner depending on functional requirements. Less complex or better-learned responses would be performed in a nonvolitional manner and be under control of the lower keyboard. Complex routines would be under the control of the upper keyboard. The ability to perform highly skilled acts would depend on the internal organization of the entire motor arrangement. The lower keyboard will respond accurately to the signals of the upper keyboard as a function of the upper keyboard as well as the close connection between the two boards.

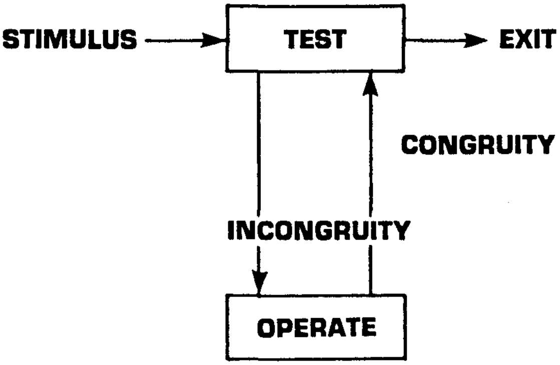
Using neurological terminology and concepts, Pailard has attempted to identify executive programs and subroutines, discussing ways in which they work dependently and more or less independently.

We will examine some representative models in which the controlling mechanism for movement behavior has been expressed as a plan, motor program, or schema. The development and refinement of such a mechanism leads to higher-level performance, as the executor changes in nature and level of control.

Plans

The idea that a plan guides behavior is analogous to the notion of a program that guides a computer's operations. Dwelling heavily on cybernetic concepts, George Miller, Eugene Galanter, and Karl Pribram (1960) developed their notions about the hierarchical nature of the organization of behavior. The basis of human activity is what these authors term plans. A plan is conceived to be a hierarchy of instructions. More specifically, "A Plan is any hierarchical process in the organism that can control the order in which a sequence of operations is to be performed" (p. 16).

Instead of talking about reflex as the basic elements of behavior, Miller and his colleagues introduced the Test-Operate-Test-Exit (TOTE) unit. A reflex is one of the many possibilities in a TOTE pattern, which is itself a feedback loop. A simple TOTE unit follows:



Where the person initiates an action, and if his or her state and the one being tested for are congruous, it is satisfactorily completed. If the states are incongruous, the action will persist until incongruity vanishes. Feedback allows for comparison and testing, and it may be in the form of information that can be used to control behavior. When a desirable state is achieved within the organism, the operations are satisfactorily performed and the test is satisfied, the organism exists and moves on to the next activity or continues the activity with increased probability.

Complex plans of activities are hierarchies of TOTE units. The baseball batter will swing, make good contact with the ball, and run speedily to first base. The whole action appears like a simultaneous series of events, controlled by a single plan. It is composed of a number of distinct phases, each with its own plan, and, in turn, subplans and more subplans. The planning stage for any activity consists of constructing a number of alternative tests (plans for action), attempting to select one that appears to fulfill the desired outcome. The operational stage contains the execution of the plan, with both tests and operations (TOTE units).

When a learner attempts to master a skill, it is assumed that there is some notion of what is supposed to happen and what strategies need be used. There is a plan. Complex tasks require integrated strategies, which are developed through extensive practice. The construction of these subplans enables a person to deal "digitally" with an "analogue" process. This comparison of human behavior to computers appears in the chapter entitled "Motor Skills and Habits" (Miller et al., 1960) and is most insightful. Digital operations are discrete — yes or no, on or off. Analogue devices produce qualitative data — variations, magnitudes, and so on. The skilled performer appears to make desirable operations to continuously varying input. The baseball pitch (speed, location) is responded to by a swing or no swing. The superb batter has learned how to translate this type of information like an analogue device because plans are formulated symbolically and digitally. A hierarchy of learning-performance strategies occurs. In the words of Miller, Galanter, and Pribram (1960), "planning at the higher levels looks like the sort of information processes we see in digital computers, whereas the execution of a Plan at the lowest levels looks like the sort of process we see in analogue computers." A motor vocabulary is established whereby well-learned skills are represented digitally. The authors feel that association and chaining theories inadequately describe this type of behavior. Skilled behavior is viewed as ongoing actions, directed toward specific situations that guide them. This behavior is organized hierarchically into units with varying levels of complexity.

Keele's Motor Program Model

The belief in a motor program that governs a sequence of movements, allowing this sequence to be executed without any peripheral feedback, is in contrast to closed-loop theory. Within closed-loop theory, the memory trace as the central mechanism of control was hypothesized. But the mechanism is limited in application to motor tasks, as it is easier to explain its involvement in slowly rather than rapidly executed acts. Yet, it is always of interest to speculate how skilled motor performance, when it is rapidly and accurately demonstrated, occurs in a short time period.

Brief movements, usually taking a fraction of a second, are typically referred to as ballistic acts. The notion of the existence of motor programs is especially helpful, as attempts are made to explain how such rapid responses occur. Because this kind of response cannot be corrected during a brief period of time, it is rationalized that it must be governed by some kind of program. It is as if there needs to be a preestablished sensory awareness in order to enact a motor program. Steven Keele (1968) believes that motor programs exist for predictable and well-learned events, such as when a person aims at and hits a target a short distance away. Such a program would act to control the direction, extent, and speed of the movements.

Movements can be controlled with the use of visual feedback and/or kinesthetic feedback if the movements are slow enough. Keele indicates that movements may be preprogrammed in that the particular muscle fibers to be activated and the timing of their innervation are determined prior to the actual movement. Control in a series of well-established and predictable movements most likely shifts from visual and kinesthetic feedback to preprogrammed conditions. Preprogramming would suggest:

1. Reduced necessity to attend to cues.
2. Increased anticipation of successive stimuli.
3. Faster possible movements.

Keele also feels that the research evidence demonstrates that movement control may become internalized, and free from visual influence for briefly timed tasks. But can good performance be shown without kinesthetic feedback? Adams speculated that movement generated a trace and that timing is based on kinesthesis. Keele (1968) raises the question of "whether the individual movements within the series are initiated by feedback from the previous movement or whether kinesthesis is used only intermittently in correcting a motor program" (p. 398). He concludes that the ability to perform movements probably depends on a motor program, as well as other cues. To Keele, Adams' memory trace is a small-scale motor or movement program. It only helps to select and initiate responses, not to monitor a long sequence of learned responses that might be executed in continuous activity.

Further elaborating on these thoughts, Keele (1973) has reported experiments that might support the notion that kinesthetic feedback functions in certain ways in skilled performance and yet not necessarily in directing controlling the patterning of movements. Insisting against a closed-loop theory (e.g., Adams') as well as against the S-R chaining concept (e.g., Gagne's motor chaining hypothesis), Keele has written that the skilled performer constructs a motor program for an activity that contains a series of predictable and perhaps rapidly executed movements. The activity is open loop in nature.

Feedback in this case does not and cannot monitor, control, or regulate such movements. It would appear, though, that feedback helps the learner to formulate motor programs. It also might initiate programs and help in the adjustment of movements in certain ways until the movements are well learned. In those movements where it is necessary continually to make adaptations and modifications to cues, learner attention is necessary for their correction. In predictable situations where corrections will not be necessary, attention and feedback need not operate for the governance of a sequence of movements.

Peripheral Versus Central Control Issues

To this point, models have been described as prepared by various scholars in which there has been a general attempt to analyze skill acquisition and performance (1) similarly across all kinds of tasks, or (2) for a particular kind of task. In the latter case, some models have been prepared to deal with continuous and fast adjustment movements. In the former case, the same model is used to describe mechanisms or processes involved in all motor performances.

It would seem logical that great similarities exist in the way we function in the learning and performing of a broad spectrum of learning tasks. The law of parsimony suggests that we look for commonalities and attempt to describe behaviors in their least common denominators. But inaccuracies occur in some cases and data are "forced" to fit the model. Why not different models for different task classifications? One might be developed to describe the processes involved in undertaking a continuously performed, externally paced task. Another model might best describe a discrete, self-paced activity. It is conceivable that other models could be developed for other categories of tasks. However, these suffice for the purposes of demonstrating similarities and dissimilarities among models that might be used to explain two different types of activities.

The externally paced continuous task requires constant selective attention to cues and perceptual anticipation of events. Perceptual anticipation includes the ideal intermix of arousal level and set for oncoming unpredictable cues. Selective attention and perceptual anticipation work together, leading to recognition and identification processes. Long-term memory, the result of previous experiences in similar situations, influences the work done by all these processes. Decision-making must usually occur instantaneously. Based on situational analysis, previous experiences in similar situations (retrieved from the storage system) and the feedback of information as to the match of performance to the situation, movements are continuously adjusted for appropriate action. The long-term memory system contains stored movement programs, with executive and subordinate routines that correspond to them. The degree to which acts have been learned will be reflected by the ability to respond as instantaneously and accurately as the situation demands, with alternative plans ready and available for use when necessary. The importance of feedback for the ongoing performance as a performance regulator is underscored.

Yet, success in self-paced, brief tasks appear to be governed by carefully made analyses of the situation, dependent on factors similar to those in the previously described task. There is much more time, however, to formulate the plan and to put it into action. Feedback in this case is in the form of knowledge of the results of performance, rather than knowledge of ongoing performance. As such, the act may be completed without any immediate function of feedback, except as an additional source of stored matter to be called on when and if the act is repeated.

There are cases where feedback can be of some value in adjusting performance in these tasks. Think of the pitcher throwing the baseball or the tennis player hitting the serve. These are relatively discrete acts in which results of performance are of no value for those events but can be employed as useful information for subsequent events. But during these acts it is possible to respond to visual or proprioceptive cues that inform the performer to some extent whether movement adjustments are necessary. A particular plan for serving the tennis ball may have to be modified upon recognition of a poorly tossed ball. While throwing the baseball, slight slippage should result in compensating movements so that the pitch is still effective. A more rapid and briefly timed movement is less apt to be regulated by feedback processes.

The emphasis on certain processes for excellence in performance in some activities and on other processes in other activities is useful information for the learner and the teacher. Instructional procedures should be geared to reflect these considerations.

A comparison of Keele's and Adams' models might lead us to accept the possibility that both types can indeed explain motor performance, especially if we categorize tasks as involving (1) extremely fast movements without time for the performer to benefit immediately from feedback, or (2) movement slow enough that feedback can assist the individual during task performance. Thus, the availability of feedback during performance becomes the central issue between the two models.

Although it is true that Adams proposes the memory trace as an open-loop motor program, operating without feedback, it is not presented and developed to the extent that Keele considers movement control to occur. Adams suggests a motor program that only selects and stimulates a response. Keele stresses its function in controlling longer sequences of behavior, as well. The position taken by this writer throughout this text is that the execution of different categories of tasks will contain commonalities for explanatory purposes as well as distinctions. In the Keele-Adams issue, preprogrammed plans could conceivably operate in Case One and closed-loop control in Case Two. This point has been elaborated on, with an extensive review of pertinent research, by Eric Roy and Ronald Marteniuk (1974).

Although Adams' and Keele's models have been compared on numerous occasions by their creators and by others in scholarly presentations and articles, and many apparently contrasting views have been resolved somewhat, still others persist. As Neill (1977) illustrates in Figure 2-8 and states, Keele postulates a "template" (a

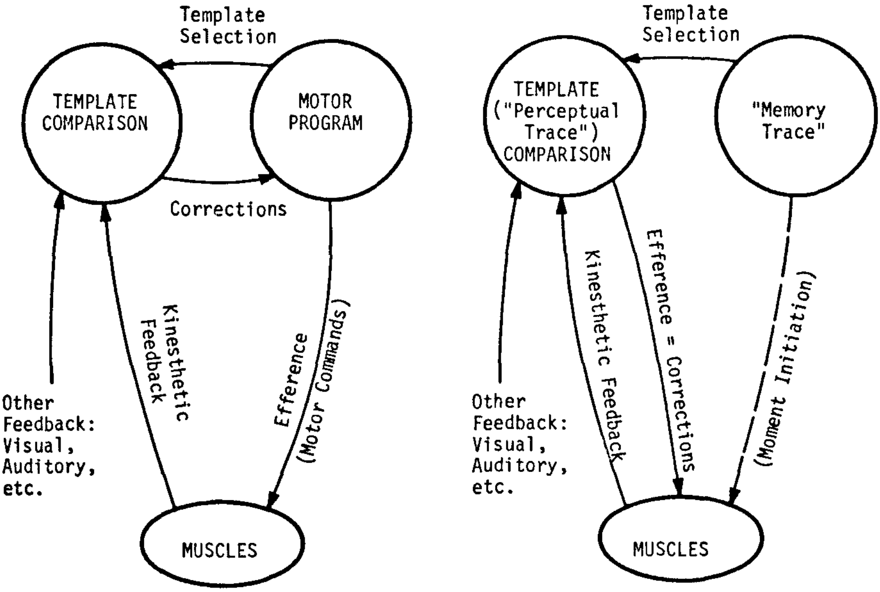


Figure 2-8. (a) A model of skill learning and a mechanism for the detection and correction of errors (adapted from Keele and Summers, 1976). Note dual (but not necessarily redundant) representation of the movement. (b) Adams' closed-loop theory, similarly represented for comparison. Details of movement are incorporated only in the "perceptual trace." (From Neill, W. T. Input and output coding in motor control: A review, Unpublished paper, University of Oregon, Eugene, Oregon, 1977).

referent model) analogous to Adams' "perceptual trace," which represents the sensory consequences of the ideal movement sequence. Adams suggests that a "memory trace" initiates a movement, whereas Keele believes that a "motor program" specifies all components of the movement sequence. Feedback from the response would be compared against the template, and the motor program would be corrected if error were determined. In essence, then, a dual representation of movement is proposed by Keele in the template and in the program. In open-loop tasks, Neill (1977) points out that theorists disagree about whether feedback is intermittently and optionally sampled or it is detected automatically to modify a planned movement. Movement programs can be executed with or without feedback, argues Neill.

Stuart Klapp (1976) makes the point that a movement may appear to be programmed or under feedback control, depending on the level of analysis. For instance, programs are probably maintained under gamma-efferent (the spindle-receptor system) feedback control. It is probably true, as Klapp (1975) writes, that "long movements are under feedback control whereas short movements are predominantly programmed and ballistic in nature" (p. 151). Feedback controlled and programmed movements are "mutually exclusive forms of movement control" (p. 152), at the general level of analysis. Yet, both forms of control may operate in either type of movement. In longer movements, for example, programs may operate. Feedback control in shorter movements is not continuous but occurs periodically in program implementation. As we can see, interpretations of what is meant by a program, or central control, and feedback, or peripheral control, encourage the analysis of movement to take differing perspectives.

Further analysis of the problem — whether skilled, rapidly performed complex movements are exhibited as a result of closed-loop (*peripheral*) control or open-loop (*central*) — has been made by Dennis Glencross (1977). He makes a thorough analysis of the literature that deals primarily with such topics as feedback latency, deafferentation and the ischemic nerve block technique, serial organization, the control of positioning movements, and delayed and augmented feedback. Glencross then suggests that the evidence does not strongly favor one position over the other. He calls for an integrated approach to incorporate the notion of a central control system and a sensory feedback system.

In this two-stage adaptive-type model, Glencross proposes that in the early stage of learning a skill, the performer is dependent on feedback (closed-loop). With skill, the performer uses a motor program (open-loop), which can be run off without any sensory or central intervention. There is an advancement of hierarchical control as progress is shown. The executive program control in the first stage is at a "lower level" than the executive control in the second stage. Obviously, there are many phases of development that must take place before the executive program is established and well honed.

Schmidt's Schema Theory

Schema theory, as proposed by Richard Schmidt (1975), contains points of view expressed earlier by others, as well as departures, in order to more adequately resolve some limitations in open-loop and closed-loop theories. In schema theory, Schmidt deals with discrete, rapidly executed tasks, rapid ballistic tasks, and open (externally paced) and closed (self-paced) tasks. He does not cover tasks of a continuous nature.

The heart of his theory is with the concept of schema, as opposed to program. Theorists usually posit a one-to-one relationship between stored programs and generated movements. Perhaps this is too much of a storage problem in the limited capacity that we possess. On the other hand, the existence of schema implies that there are "generalized motor programs for a given class of movement" (Schmidt, 1975, p. 232). These schema, or the sets of rules, would not take up so much storage space, and could help to explain one's ability to perform somewhat novel tasks or old tasks in novel situations. This ability would be related to the degree to which a schema is developed for a particular movement category and the width of the category.

As was the case with Adams' work, Schmidt's theory has been instrumental in stimulating much research by motor behaviorists. As was indicated at the beginning of this chapter, the mark of a good theory is that the hypotheses in it are testable. Many researchers have attempted and are still attempting to determine the validity of these hypotheses with various tasks and under varying conditions.

Schmidt (1975) proposes that four sources of information are stored together by a person after a purposeful movement is attempted. A schema is developed from the arrays of information from these sources as movements become more effective. Schmidt refers to such stored sources as: (1) knowledge of the *initial conditions* (state of the organism and environment), which is used preparatory to activity; (2) knowledge of the *response specifications* (movement requirements), which is used before executing an act; (3) *sensory consequences* (response-produced sensory information without a value judgment); and (4) *response outcome* (the relationship of the performance to the intention), derived from internal and/or external sources of feedback. These sources of information, which contribute to the formation of schema, are presented in relationship form in Figure 2-9.

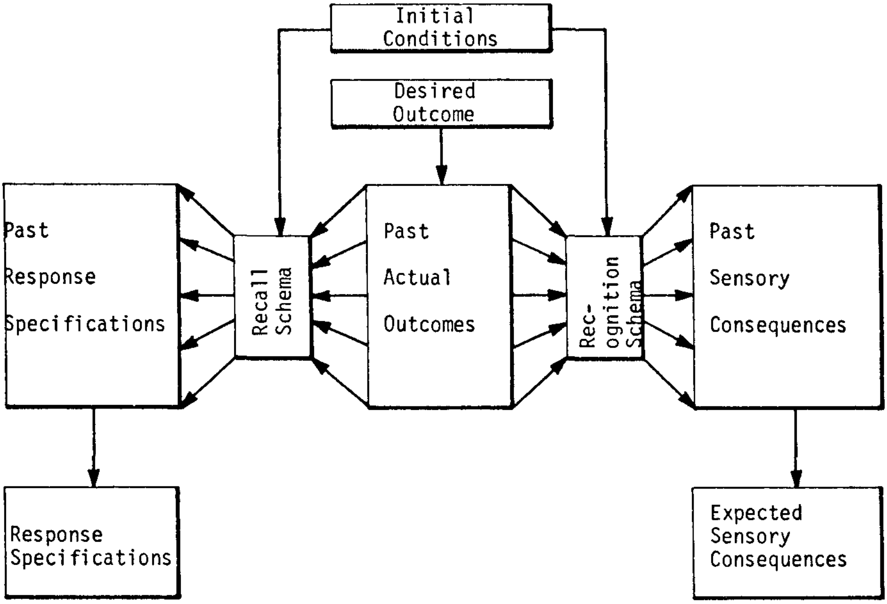


Figure 2-9. The recall and recognition schema in relation to various sources of information. (From Schmidt, R. A. A schema theory of discrete motor skill learning. Psychological Review, 1975, *82*, 225-260). Copyright 1975 by the American Psychological Association. Reprinted by permission of the author.

Recall and recognition schema are also identified in Schmidt's theory (see Figure 2-9). *Recall schema* are formed from the relationship between previous response outcomes and response specifications and help the performer to determine what should be done to complete an act successfully. The relationship between the actual performance outcome and the sensory consequences represents the *recognition schema*. The recall and recognition schema presumably involve distinct processes.

Both forms of schema are dependent on the actual outcome and the initial conditions, but while the recall schema depends on the response specifications, the recognition schema uses obtained sensory consequences. Knowledge of results affects the recognition schema, not the recall schema. Both these schema will develop in relation to the experiences had with these variables. Increased amount and variability of practice will lead to the formulation of increasingly strong recall schema, as well as recognition schema (Schmidt, 1976). Therefore, the schemas may not involve totally distinct processes.

It is instructive to read Schmidt's works for his own criticisms and questioning of his theory, as well as Adams' (1976) for his arguments in favor of his closed-loop theory. In this way, a greater appreciation can be realized of the many considerations that need to be addressed on an empirical basis if motor behavior concepts are to be accepted fully.

SUMMARY AND COMMENTS

As we have noticed, the trend in theory and model development associated with motor skills has indicated less reliance on association (S-R) models and more dependence on adaptive, communication, and control models to describe the nature of skill acquisition. Nevertheless, each approach emphasizes factors that the other does not. Some are deeply embedded in behavioral science, highly dependent on experimental findings, and intended to contribute to basic theory. Others are far more general and descriptive, with obvious ramifications for teachers and learners.

The purpose of this chapter was to discuss theories and models of behavior, how they contribute to our knowledge, and how they have been derived as dissatisfaction with general learning approaches to explain processes involved in skilled acquisition increased, other ways to examine them were developed.

Although the distinction often is not clear, and the terms theory and model have been used interchangeably in the literature, theories have tended to be associated with more general attempts to explain more of behavior than have models. Models have usually been more restricted in scope and concentrated in effort. Conceptual trends in understanding behavior reveal that the popularity of general learning theories has given way to the much needed development of models and more constrained theories that can specifically deal with aspects or particular types of learning and performance.

Theories overlap or are distinguished by emphasis on unique features. For some scholars, it is the contiguity of the correct response to a given stimulus. Skinner, although nontheoretical in experimental procedures and admittedly against the notion of theories of learning, is associated with reinforcement, the Gestaltists with perception and cognition, and cybernetic theorists with feedback loops. Theories differ in vocabulary. Stimulus-response, input-output, reinforcement-feedback, and other terms serve to distinguish methods of analyzing the learning process.

Both generalized and specific theories have their respective values. The more general theories provide general laws of learning, consistent over a wide assortment of learning materials. Specific theories are concerned with particular situations and therefore apply more adequately to those unique problems associated within the area of interest. Learning theorists have been interested primarily in verbal learning and classroom methodology. More recent developments indicate trends in which dissatisfaction with traditional theories has resulted in theories of communication and control.

The current emphasis on going beyond S-R analysis, on identifying those intervening variables that influence performance, and on determining the relationships of mechanisms and processes is healthy and fruitful. Systematic approaches to model development clarify such considerations.

It needs to be reiterated, however, that the true value of theories and models lies in their ability to generate workable and testable hypotheses for research efforts. Naturally, the more data that are available to support a particular set of beliefs, the more acceptable the models or theories. They should stimulate and generate research. If not, much of their value is lost. Many of the theories and models presented in this chapter help us to understand behavior more adequately, but by the same token, a number of them are so vague and general that they cannot be proved wrong. They do not encourage specific testable research hypotheses. They are logical and interesting approaches for the analysis of behavior but need to be laid out in a more specific and sophisticated fashion. If that is done they will be meaningful for practical purposes and at the same time act as a stimulant for research efforts (e.g., to see if behavior can be predicted from them).

Adams', Schmidt's, and Keele's models can be contrasted with Gentile's model, for instance, in the following way. The first three have been developed with scientific scrutiny and allow and encourage experimental work that might substantiate or refute their basic tenets. The latter is more general and descriptive and is geared primarily for the teacher of skills. From these perspectives, each has an important role to play.

I have deliberately avoided taking a stand on evaluating each approach described in this chapter. My purpose has been to familiarize the reader with early and contemporary efforts in theory and model development. The serious scholar will readily see that many of the conceptual approaches contain statements and descriptions that are quite elusive, evasive, and general.

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Chapter 3

Applications and Implications of Theoretical Psychomotor Learning Models For Industrial Arts Education

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PSYCHOMOTOR SKILLS AND INDUSTRIAL ARTS

Successful teaching of psychomotor skills has always been of concern to industrial arts educators. From our beginnings in the Manual Training Movement, we have believed that students can learn to be technologically literate only by actually experiencing the activities and processes of a technological society. When we teach students, we want them to learn psychomotor skills because we believe that through the success experience of improving in specific skill areas, they will become better motivated and enabled to learn other things, as well. We agree on three basic notions: (1) learning is enhanced by activity; (2) to engage in activity successfully one must develop a level of psychomotor skills; and (3) psychomotor skills can help develop an appreciation of tasks and processes. It is important for the future teacher of industrial arts to have a good deal of skill in the operations which are typical of industrial arts instruction. Only in this way can those operations be properly demonstrated to students. Clearly, therefore, a useful perspective on pyschomotor learning is essential to the teacher of industrial arts.

This chapter is offered as a response to Singer's chapter from an industrial arts point of view. It seeks to accomplish three goals. *First*, it will describe the psychomotor skills themselves in terms of the operational definitions which are contained in the major theories of psychomotor learning that Singer presented. These definitions will be given, as far as possible, in terms of their application to industrial arts. *Second*, it will examine most of the theories described in Singer's chapter as they stand alone as conceptual contributors to principles which might be implemented by teachers, and also as they contain commonalities which may be abstracted to instructional situations which are likely to be encountered. *Finally*, it will present some operational suggestions derived from the major theories of psychomotor learning and from comments of contemporary authors. This list of prescriptive suggestions should be valuable to those who study, practice, and learn within the profession of industrial arts.

Before beginning the discussion, however, it is necessary to achieve a rather precise understanding of the operational characteristics demonstrated by various motor learning tasks with which we may find ourselves involved. This information will be helpful in understanding and synthesizing later concepts.

Psychomotor skills should be classified into several categories according to their characteristics (Shemick, 1977). These categories may be descriptive of the skills themselves, the temporal or physical manner in which the skills are performed, or the relationship of the skills (and the performers) to the environment. Most classifications of psychomotor skills are based on the notion of continua along which the characteristics of a particular psychomotor skill can be described. All skills can be fitted to a position in one or more of these classification schemes. Although there may be some overall relationships among the classification schemes, no attempt at a unified classification approach is made here. It is probably sufficient to remember that motor skills are similar to — as well as different from — one another in several respects. With that in mind, the classifications important to this discussion are: (1) precision of movement, (2) temporal characteristics, (3) environmental influences, (4) individual control, and (5) feedback.[1]

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[1] There are other approaches to psychomotor skills classification. For example, Shemick (1977) proposed a taxonomy of psychomotor skill tasks which may be analogous to Bloom's (1956) taxonomy of educational objectives. He stressed the importance of differentiating psychomotor tasks by their characteristics.

PRECISION OF MOVEMENT

When psychomotor skills are classified according to the precision of movement involved, they may be considered as either gross motor skills or *fine* motor skills. Gross motor skills (lifting a 2x4) involve large muscle movement and tend not to be as precise as fine motor skills (repairing a watch). The latter involves small musculature, precise movements and hand-eye coordination. The former utilizes large muscle groups and usually permits a greater margin of movement error.

TEMPORAL CHARACTERISITCS

One way to classify psychomotor tasks is by the precision with which their beginning and ending points can be described. Tasks which have clear beginnings and ends are *discrete* skills. Energizing a switch would be an example. The movement begins, the switch is activated, and the task ends. If the task is larger and is made up of several discrete tasks, it becomes a *series*. (Typing a letter would use a series of discrete tasks). In cases where the task is a longer-lived act which has no clear start and stop points and is in response to an external stimulus (or stimuli), it is a *continuous* one, such as driving an automobile. Discrete and continuous tasks have different instructional implications, and may require different approaches by the teacher.

ENVIRONMENTAL INFLUENCE

Psychomotor skills may also be classified according to the degree to which they are motor oriented or subject to the processing of perceptual information. Some tasks require repetitious, automatic behavior which is best improved by achieving consistency of action. Examples of this might be operating a paint spray gun or sanding furniture. Such tasks have been described as requiring *closed* skills. Others involve a high degree of perception and adjustment in the movements resulting from the changing environment. Because they are subject to continued modification they are called *open* skills. Using a jig saw to cut a curved line or turning bar stock to specifications might be considered open skills because they involve a continuous modification of the activity by the learner. The concept of closed or open *skills* is very different from closed or open *feedback loops*, as will be shown later in this chapter.

INDIVIDUAL CONTROL

The extent to which the learner is in control of the timing or manner in which the task is to be performed is another classification scheme, one which is related to the closed or open nature of the skill itself. Closed skills tend not to be interactive. That is, they are passive in nature and wait for the action of the performer before they can begin. For example, hitting a golf ball is a closed skill. By contrast, open skills, because of their environmental interaction, require the performer to act upon some stimulus which is already occurring, as exemplified in the act of catching a fly ball. It can therefore be seen that a closed task enables a self-paced mode of activity to occur. The learner is the initiator. An open task would require an externally paced activity, since the learner is the responder.

The Feedback Issue

Two kinds of feedback can occur with psychomotor performance: open loop and closed loop feedback. Open loop feedback occurs in short duration activities when the feedback is not used to alter the action once it has begun, but is somehow used to plan the next repetitive response to the stimulus. Again, the golfer is a good example: the swing, once begun, is carried through in open loop fashion. Feedback in open loop occurs in post-performance analysis — and without analysis, there is no feedback. Unfortunately, wrong habits can be — and often are — practiced and become more ingrained through open loop feedback. On the other hand, closed loop feedback implies instant environmental influence on the learner's response to feedback. The baseball player discovers this as he (or she) attempts to catch the ball. In closed loop feedback, the individual makes ongoing adjustments in the activity by virtue of the information derived from the outside feedback (by moving to where the ball appears to be headed). Thus, closed skills may be associated with open loop feedback, and open skills with closed loop feedback.

AN ATTEMPT AS SYNTHESIS

It might be helpful to visualize psychomotor skills classification as a three-dimensional model in which skills are arranged according to continua which describe the size of musculature or precision of movement involved (fine-gross), the nature of the feedback (open-closed), and the length of the performance (discrete-continuous). Figure 3-1 provides a representation of psychomotor skills which portrays

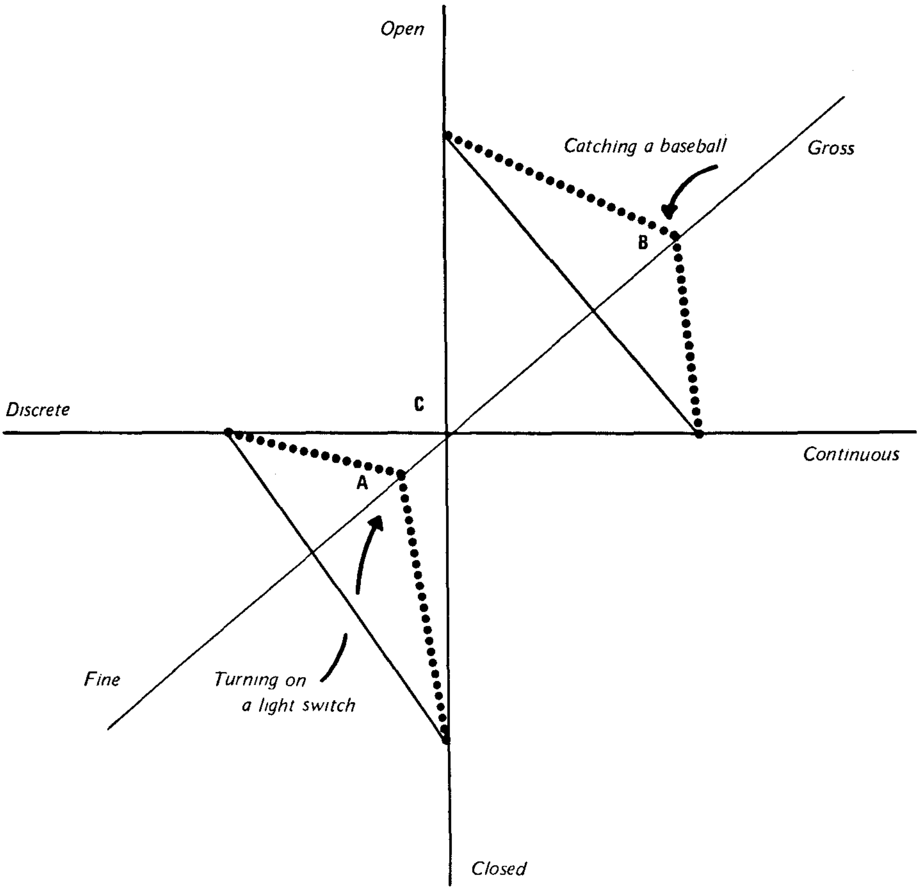

Figure 3-1. The position of three representative psychomotor skills on the three dimensions of fine/gross, open/closed, and descrete/continuous skills.

all these dimensions. Operationally, any activity could be described as a plane which intersects somewhere on this model. The previous example of turning on a light switch is located at the position indicated by (A), since it is a rather fine, discrete, open feedback skill. On the other hand, (B) plots the position of catching a baseball by that activity's characteristics. It is a more gross psychomotor skill, and is characterized by continuous closed feedback activity. Therefore, it shows up on the other side of the model. If another task were plotted which fell at the exact midpoint of each of the three continua, it would be located at the point (C) where the three lines intersect and would require a perfectly balanced skill to perform it. Most tasks, and the skills required to perform them, are not so nicely balanced.

Since the three skills just described are so different in nature, it seems logical that they should be taught differently. Intuitively, different instructional procedures seem appropriate for the various skills. We are beginning to learn more about this phenomenon. As psychomotor learning stimulates research, a mosaic of data is developed upon which prescriptive educational techniques may be based. For example, we now know that certain types of skills do indeed respond differentially to various instructional styles (as will be reported later in this chapter). Some day, psychomotor learning data may be so well organized that merely by classifying the task with respect to several significant characteristics and evaluating the environmental parameters, as well as individual learner characteristics, the instructional designer will be able to identify the teaching strategies which will be most cost-effective for the learner on any given task. Until then, we are likely to rely on the existing theories for a conceptual framework of psychomotor learning, and the teacher's professional knowledge and experience for proper application in the classroom or laboratory.

THE EDUCATIONAL IMPLICATIONS OF GENTILE'S MODEL

In this observer's opinion, the model of learning proposed by Gentile (1972) has not been given the attention it deserves by industrial educators. It is often passed over in the literature with only a cursory explanation or brief statement. However, it should not be so lightly dismissed. Gentile's theory is noteworthy because it attempts to explain psychomotor learning behavior in such a way that direct applications can be made to teaching. If teachers can understand Gentile's theory, they should be able to successfully use it to help teach psychomotor skills even if they do not understand all the psychological, neurophysiological, or research data from which it was developed.

Gentile's theory is based on the assumption that psychomotor learning can be divided into two different kinds of tasks (Holding, 1965; Knapp, 1961; Poulton, 1957). One type involves skills which occur in relatively fixed and unchanging conditions. They have been characterized as being largely motor oriented because they depend on movements which are repeated time after time and tend to become habitual (Drowatzky, 1981). Once mastered, very little modification or fine tuning is necessary for efficient performance of the task. The proper manipulation of a hammer to drive nails in fastening lumber is an example of this. While the nails might be driven in a variety of physical and contextual situations, the basic skill involves repetitive actions which are almost exactly the same, and require little ongoing adjustment because the cues observed by the learner change very little during the activity. This is an example of *closed* skills. The stimulus is *passive* and waits to be acted upon by the learner.

At the other end of the continuum are skills which take place within an ever-changing environment. They require the learner to maintain constant vigilance over the ever-changing cues while the action is occurring, and make constant changes and modifications to his or her behavior so that the action always approximates that which is desired. Repetitive or habitual behavior may not be useful in a constantly changing environment because the circumstances are qualitatively different. Here, the stimulus is active, and requires the performer to modify it even as he or she is reacting to it. Such activities are termed *open skills*. Cutting a compound curve with a band saw is an example of open skills. As the degree and direction of the curve change, the performer must make continuous adjustments in angle, pressure, and rate of feed of the work so that the pattern can be followed. Figure 3-2 illustrates the way in which open and closed skills are used in Gentile's theory.

The way the activity is generated, or paced is yet another way of looking at open and closed skills (Magill, 1980). In closed skills, the passive stimulus may be considered to be "waiting" to be acted upon by the performer. Nothing happens until the performer acts, and the performer begins and ends the activity at will. Thus the closed skill may be considered a self-paced task, whereas the open skill takes place in an environment which changes with respect to space or time, and therefore forces a reaction from the performer to each changing component of the activity. Because of the interaction between stimulus and response, the more open skills are known as *externally-paced* or *forced-paced* skills.

The concept of skills as open or closed is an important one, and has been used by many researchers and theorists in the study of motor learning. Gentile's contribution is important because of its relevance

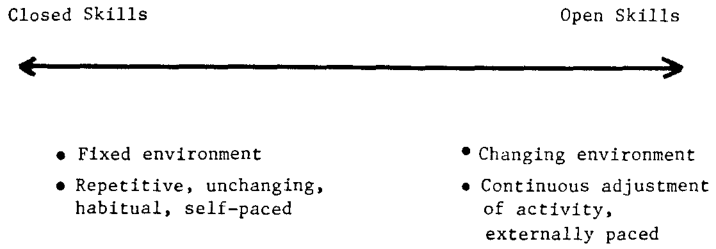

Figure 3-2. A continuum of open and closed skills as used in Gentile's theory.

to the implementation of instruction in realistic situations. She made the important observation that since the open and closed skills were in fact very different, they should be taught differently for the best results.

Gentile uses two stages of skill development to explain the learning of both open and closed skills. In "Stage I: Initial Skill Acquisition," a movement pattern is mastered which generally approximates the skill to be learned. Here, the individual focuses on the general idea of the movement and "tries it out." Then, in the second stage ("Stage II: Fixation/Diversification"), the skills are fine-tuned or honed to the specific level desired. With closed skills, the movements become very stable and consistent (Fixation). They vary little if at all throughout different replications of the skill. Open skills are treated differently, since they require differentiated responses to constantly changing stimuli (Diversification). The learner needs a larger repertoire of learned skills which can be brought into play as needed to maximize control through a dynamic relationship with the stimulus.

In discussing the two-stage learning process, Gentile makes some interesting distinctions. The first is the differentiation between knowledge of results and knowledge of performance. Knowledge of results refers to information about the degree to which the goal of the behavior has been attained. Knowledge of performance refers to knowledge about the actual movement or activity which has occurred. For closed skills in Stage II (Fixation/Diversification), augmented or additional information about knowledge of performance might be most helpful to the learner. But, the kind of information that is helpful is different for different kinds of skills. For closed skills, the most appropriate elements of the performance itself must be explained very specifically to the learner. The situation is different, however, when dealing with open skills. Given the changing conditions in an open activity, the student might better profit from additional information about the extent to which the desired goal has been achieved. Since many behaviors — indeed a repertoire of response patterns — may be used in response to open skill problems, information about how well the response which the individual selected was able to achieve the goal would seem to be of greatest value to the learner.

The second important notion is the initial cognitive component, which Gentile terms "getting the idea of the movement." It is differentiated from the cognitive components that are used in formulating the motor plan. In the initial cognitive component, an organizational schema is conceptualized by the learner for performance of the task at hand. The learner uses this schema, or image, to foresee the actual psychomotor activity that will be necessary to accomplish the task. It seems obvious that if psychomotor learning does occur in the type of sequence envisioned by Gentile, it will be very important for the teacher to help the student develop a motor plan which stresses those behavioral components that will most likely lead to a successful and reinforcing initial experience. In this way, negative responses can be avoided, and the student can progress to higher levels of competency.

For industrial arts, the main contribution of Gentile appears to lie in her attempt to integrate what is well known about psychomotor learning into a cohesive sequence applicable to instructional design, and to suggest that different skills should be taught differently. The teacher is considered to be a central figure in the instructional sequence, an arbiter of learning strategies. Such a model of learning recognizes that enlightened decisions must continuously be made by the teacher concerning the level of instruction, the number and complexity of inputs to be provided, and the number and nature of auxiliary information to be provided. It is not really important to us whether Gentile's model is a general one, as described by Singer in his chapter, or an information processing one as described by Whiting (1972) in his evaluation of the model. What is important is the degree to which the concepts deriving from Gentile's work can be effectively used in the classroom or laboratory to help students master important motor skills.

THE ADAPTIVE MODELS: A HIERARCHY OF PSYCHOMOTOR LEARNING

In the preceding chapter Singer considered several such approaches which he judged to be adaptive or hierarchical in nature: Plans, Keele's Motor Program Model, those theories involved in the controversy over peripheral versus central control, and Schmidt's Schema Theory. This section will attempt to summarize approaches made by many of the theories, describe their differences and commonalities, and offer some unifying thoughts for teachers.

THE PLANS MODEL AND THE MOTOR PROGRAM MODEL

Several theories of psychomotor learning hold that the mechanism for learning skills — and reproducing them at will — is contained in a series of activity programs which operate at various levels of complexity. Each large activity is governed by a major program (sometimes called an *executive program*) and is composed of subprograms which account for different portions of the activity. These in turn lead to other subprograms. Some of these subprograms (subroutines) are thought to be irrevocable once started, and are measured in duration of thousandths of a second. Others are more lengthy in nature. What they have in common is the hierarchical nature of the process. Each subroutine is a necessary component of the next, and must be completed before the following one may begin. Higher level activities occur as the individual varies the level of control. A good example is driving an automobile. There are subroutines for activating the lights, wipers, turn signals, clutch, brake and wheel, but they must be strung together in a coherent whole. For a specific example of a driver's set of subprograms, see Schmidt (1982: 583). Because the subroutines are strung together to accomplish a goal, these theories have been termed adaptive (or cybernetic) models.

Scholars who support the notion that plans guide the conduct of psychomotor behavior have both commonalities and differences with those adopting Keele's model of motor programming, which will be discussed later. The commonalities lie in the hypothesized existence of some sort of pre-existing set (or a predisposition) for the governance of behavior. In both models, the actual performance is determined by the characteristics of this set and evaluated according to it. They differ in two major areas: first in their approach to the timing of modifications to the original program, and second in whether control exerted is internally or externally based.

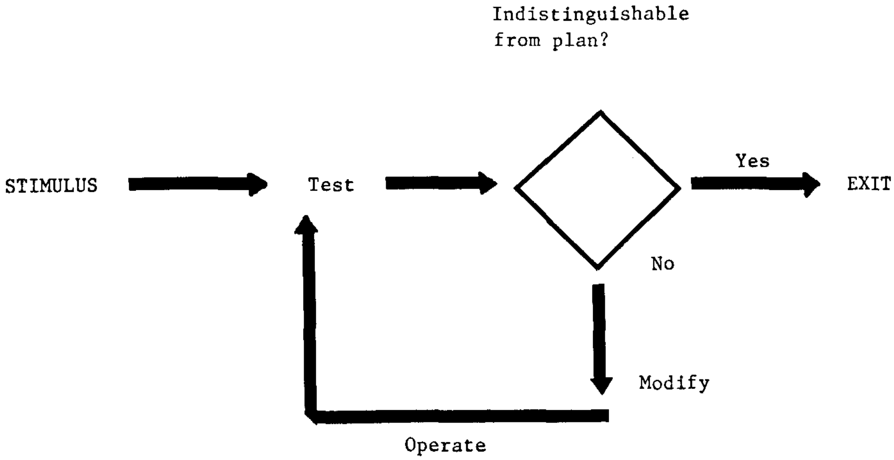

Figure 3-3. An example of a "TOTE" feedback loop as it affects the modification of ongoing activity.

The plans theory suggests the continuous modification of activities as the performance occurs by comparing the action to a previously accepted test standard. It uses what might be termed a state of perceptual dissonance to account for the individual behavior changes. Further elaboration upon this concept used the TOTE unit ("Test-Operate-Test-Exit"), which this observer calls a TOTE log (Gentile, 1972). It is a kind of feedback loop and is illustrated in Figure 3-3 as a simplified version of Singer's tote unit. For each action, repeated attempts are made to conduct movements so that the individual's perception of performance is indistinguishable from the plan. When this occurs, the activity is perfected and attempts to master it cease.

Gentile (1972) used this as a part of her mathematics teaching approach to skills learning. It would also be applicable to learning psychomotor skills.

> For our discussion, the important aspects of the TOTE concept are that (1) an image or plan of movement exists prior to execution; (2) information concerning the output is fed back to be matched against the plan; and (3) the evaluation of the "Feedback-Plan" comparison guides in the execution of the movement and determines at what point to terminate further action. The plan may or may not be amenable to alteration during execution as a function of the temporal characteristics of the movement and the complexity of the error (mismatch) signals. Modification of the output to attain congruity with the plan may only be possible on the next attempt. (Gentile, 1972:8)

Thus, the plans approach allows for the modification of ongoing activity by keeping a log of the perfect activity and the best approximation of it at any given moment.

Not so with Keele's (1968) motor program model. Here, a program exists within the brain for the execution of the skill. Action may unfold with little or no benefit of ongoing modification unless it is extremely slow in occurring. The movements are not regulated by feedback, but by the built in motor program. Such modification as does exist is exercised through anticipation of approaching events and the calling up of appropriate programs and subprograms to meet those contingencies.

At this point, it may seem that educational techniques should be quite different depending which of these approaches is used. However, there is another fundamental difference in these two theories which is quite beyond the issue of feedback and adjustment timing. That is the controversy of control location for whatever feedback does occur. Does feedback and motor control have an external (peripheral) source, as might occur with plans, or does feedback derive from an internal (central) source, as provided for by Keele's model? Unfortunately, available answers to this question may only serve to cloud the issue.

In addressing this problem, a clarification of terms is in order. The terms "open loop" and "closed loop" have been associated with different philosophical approaches to the nature of feedback orientation. The problem is that the terms are confusing, and not easily understood by their apparent meaning. Recall that open loop and closed loop concepts are not part of the same descriptive taxonomy as the previously discussed open skills and closed skills. The *closed loop* theories hold that external stimuli are fed back through the learning model to enable the individual to bring actions into congruence with externally derived standards. The *closed loop* model therefore does not imply isolation of the individual from the immediate environment during the learning process. It implies an interactive activity. Conversely, the *open loop* approach is associated with central control of feedback in which rather complex behavior occurs sequentially without benefit of peripheral control. Thus, actions may be governed based on feedback from previously memorized actions rather than immediate results. The case is made for relatively quick actions as subordinating to open loop control. Plans, therefore, involve closed loop control because they are composed of externally generated stimuli, while Keele's model would have us use an open loop system as we respond to internal stimuli.

This issue has never been adequately resolved. In discussing current implications of peripheral versus central interpretations of learning, Tighe (1982) observed that the most fundamental question in learning theory

> . . . concerns the *nature* of central mediating processes — should these processes be conceived of as following the same laws as observable stimulus response relations or as following different laws? Present day cognitive psychology has emphatically rejected the first alternative. It is the premise of present day cognitive psychology that central processes transform stimulus input in ways that destroy direct correspondence between observable inputs and outputs.

And so the controversy rages. Probably the best that could be done at this point is to suggest that the learning of different types of tasks (self-paced or externally paced, brief or lengthy, gross or fine muscle) cannot easily be explained by a single model. We must be eclectic in our approach.

THE SCHEMA APPROACH

Into this controversy steps Schmidt (1975, 1982) with his "schema" theory. He makes a valiant attempt to draw some commonalities from various approaches into a defensible model. In so doing, he proposes that motor learning is based on a series of abstracted or generalized sets of rules for behavior. These generalized sequences are based on four types of information: (1) initial conditions of the individual and the environment, (2) specifications of the response to be made, (3) results of the response which was made, and (4) the outcomes of the response compared to the desired outcome. His contribution is noteworthy because it provides for external (closed loop) feedback *as well as* internal (central) control. It also has an intuitive appeal because the act of learning may be represented by a matrix system in which all of the above are weighed, evaluated, and acted upon. The schema theory suggests that for tasks that are changing, varied experience will help the learner develop schemas (rules) that have the widest usefulness in future psychomotor learning. Further, it holds that variability in practice activity provides a widely based set of experiences which will reduce the error that occurs when new psychomotor tasks are to be learned by the individual. In this way it seems to support the general education approach of industrial arts wherein students learn a broadly based set of procedures and techniques. If the schema approach is correct, students with a broadly based industrial arts background will be successful in different related fields more often or more easily than their counterparts who have had experience that is more limited in scope.

THE IMPORTANCE OF HIERARCHICAL CONTROL MODELS

The preceding theoretical approaches to motor learning — Plans, Keele's Motor Program Model, and Schmidt's Schema Theory — have in common a belief that motor learning is based upon a set of sequential performance systems that lead from simple to complex behaviors as they are strung together, and that each one leads to the next in a meaningful order. For industrial arts, the method by which this is accomplished (closed or open loop, etc.), interesting though it may be, is not nearly as important as the overall implications of what these theories tell us. They indicate that if learning strategies are to be congruent with internal processes, they need to be presented in a particular sequence. The parts must come before the whole, and must be presented so they can be mastered in prerequisite order. Note that the sequence is not "simple to complex", but "in prerequisite order". This is important because what is simple is not necessarily first in prerequisite order, and vice versa. Prerequisite order supposes an order of presentation in which each subtask may be mastered and added to previous ones so that the student is enabled to perform more complex tasks. It might be better to say that these theories lead us to present psychomotor learning tasks to the learner in enabling order for skill development.

HOW INFORMATION PROCESSING (COMMUNICATION) AFFECTS PSYCHOMOTOR LEARNING

Some theories of learning psychomotor skills focus upon the capacity of the individual for handling and processing information. The basic idea behind these notions is somewhat familiar to those who have studied communication. Within a given group of individuals, the effectiveness of action taken by the last listener can be no more relevant than the cumulative accuracy of information passed on by previous listeners. As every individual receives information, he or she processes it, interprets it, changes it in some unique personal way, and then acts upon it. The information itself is changed by the very act of interpreting and processing, so the inaccurate gossip heard at the end of the line may be very different from what was first said as actual fact.

These theories are also concerned with the amount of information that can be processed by an individual and translated into appropriate psychomotor activity. They contain the concept of sensory overload. For example, it is not so difficult to rub one's stomach in a circular motion, or to pat one's own head. But to do so simultaneously is a task which is very difficult for most of us, simply because we are forced to concentrate upon doing both acts at once. We are awed by the sight of the performer who can do both of them while balancing on a ball with one foot while spinning a loop on the opposite ankle. As observers, we are struck by the *Gestalt*, the whole form or configuration, that presents itself to us. But in another sense, we must put these tasks into perspective. Each one is a relatively open-loop activity, polished by continuous practice, and fine-tuned to a high degree of accuracy. Singly, they are not difficult but are, in the aggregate, astonishing. The key concept here is that they have, over time and practice, become automatic. The performer does not have to *think* at all about the actions performed. He or she just *does* them.

Most of us think that we cannot duplicate the feat described above. But we do succeed in performing one almost every day which is perhaps more complex, and has much more serious implications. We drive automobiles. If we are experienced drivers, we are capable of simultaneously observing a constantly changing set of visual stimuli from the windshield, the dashboard instruments, the side and rear view mirrors, and integrating that information with motion sensation, auditory sensation of noise, and a "feel of the road" through the steering wheel. At the same time, we are capable of maintaining a constant speed and keeping the car safely on the road or driving through city traffic while operating a complex system of accelerator, clutch, brake, gears, turn signals, and steering wheel movements. And, wonder of wonders, we are even capable of doing all this *automatically*, sometimes daydreaming at the same time.

But, we did not *learn* all this at the same time, say the information processing theorists. We learned separately about the use of the accelerator, then the brake, perhaps the clutch and the turn indicator, and then put them together. When that was mastered, steering finesse was added, and so on. The complex systems were broken up into digestible parts because each time a part was being learned, all the information that dealt with its operation had to be processed. That caused uncertainty. As the system was learned and the task was mastered, the uncertainty vanished since new and unfamiliar information was no longer being processed, and we could turn our attention to learning additional tasks.

These two concepts are additive in nature. When we wish to learn a psychomotor task, we must use our internal information processing mechanism to sort out and identify the appropriate perceptions for action. Then, through a process of interpretation, it is necessary to make sense out of the perception and convert it into a program for activity which makes sense. At the same time uncertainty is reduced by building more and more fairly well developed skills into the repertoire, which in itself will change somewhat our interpretation of the stimulus (or stimuli). And so it goes. Input is indeed related to output through the mechanism of internal information processing. Unfortunately, this activity cannot be directly observed. It can only be inferred from behavior or performance.

In the same way that product evaluation techniques permit an automotive technician to observe the proper functioning of a tuned-up automobile and to make judgments about the process used in making the necessary tune-up adjustments, we are able to make inferences about the communication processes that mediate behavior. It is often tempting to try to avoid dealing with constructs that cannot be directly observed, but therein lies the opportunity. Through an operational understanding of the way in which learners process and interpret information, prescriptions may be obtained for enhancing learning. If teachers can present information in such a way that it complements the ongoing mechanism of translating information to action, they can become much more efficient managers of learning.

This may be especially important in the teaching of psychomotor skills that tend to be open in nature or that have serious safety implications. Where time is an important consideration in the application of a particular skill, it is appropriate for us to consider means of increasing learning efficiency. In both cases, the paradigm suggested by Drowatzky (1982) provides a useful perspective. He makes the case that a number of fairly complex operations must be completed in the initiation of physical activity. Some of these operations are mental and others are purely physical. All take time and contribute to the inefficiency of a given activity.

Information processing theorists such as Welford (1968, 1976) and Whiting (1969, 1972) take positions which are consistent with this view. When dealing with motor problems, they suggest that both external and internal stimuli are processed and integrated with memory. The extent to which a learner can respond appropriately depends to a large extent upon decision making capacity, which in turn is dependent upon individual differences and environmental influences.

As all teachers are aware, human performance may vary widely as a result of individual differences. Many theories of psychomotor learning do not appear to take this into consideration as they explain the mechanisms which influence learning behavior. A void, an unexplained gap, remains in the explicable determinants of learning. Surely, no theorist would be presumptuous enough to suggest that hereditary endowment and physical capability do not strongly affect the individual's capacity for psychomotor learning. Yet, to omit it from theory seems tantamount to such an admission. Whiting's model is an exception. His primary works (1969, 1972) described a model that provides for differences in performance due to individual endowment as well as differences due to conditions of learning and environmental influence. In his paradigm, performance is circumscribed by the environment, the body boundary, sense organs, and the muscular system. The problem is that when these components are placed into a composite model, it is not possible to accurately represent their proportional influence upon performance. After sixty years or so of the nature-nurture issue, as the psychologists call it, it is still not clearly resolved. What might be said today with some degree of accuracy is that natural endowment in all probability sets the parameters for physical ability and engenders within each individual certain predispositions. Within the educational framework these are conditions that we must live with, since we are not at all capable of affecting the hereditary predispositions of our students. Nor, for the most part, are we able as teachers to significantly affect their home environments. What we can do is to make allowances for these components as we attempt to teach psychomotor skills and performances. Whiting made a useful contribution to industrial arts by reminding us that in the theory and practice of teaching psychomotor skills, the individual differences of students must be considered.

CYBERNETICS AND PSYCHOMOTOR LEARNING: THE CLOSED LOOP NOTION

When the word "cybernetics" is mentioned, most of us tend to think of the rapidly burgeoning computer industry, and the complex mechanisms of equipment controlled computers. Actually, this is not far from the truth. Cybernetics refers to a system that is self-regulating and goal directed. It implies that a regulatory mechanism is present and that it approaches a pre-set goal by some method of successive approximations. Further, it implies a closed-loop system where a particular goal is attained through successive approximations and feedback activities.

Any system which has those three characteristics — goal directed, self-regulated, and controlled activity through feedback — is a cybernetic system. The thermostat in our homes and buildings is a good example. It is preset to a given temperature — say 68 degrees. As the temperature drops, the temperature sensing mechanism activates a switch that energizes the furnace. As the temperature rises, the thermostat responds by shutting off the furnace at the previously identified setting. Thus, a relatively stable temperature is maintained. It is important to note, however, that this temperature is not exact. It will vary within a range, depending upon the sensitivity of the temperature sensing mechanisms. Normally, manufacturers try to obtain a mechanism sensitivity inside the just noticeable difference (JND) of humans for temperature. When they fail, the room seems always to be too hot or too cold.

Psychomotor learning in humans, the cybernetic theorists contend, occurs in a similar manner. An activity is selected for performance, and goals are established for standards of performance or quality of results. Attempts are made at performing the activity, and the results are compared with the standard. If first results vary from the goal, as they normally do, changes are made in performing the activity to conform more closely with the desired norm. Results of each change are part of the feedback loop to enable the performance to successively approximate the desired standard. When feedback loop information indicates that the actual performance is indistinguishable from the desired behavior, that skill becomes replicable and has been learned. Bernstein (1967) describes this as doing away with the less efficient and effective behaviors and focusing upon the ones that solve the problem. Adams (1968, 1971, 1976) focuses on a shift from behavior guided by knowledge of results from someone else's experience (the verbal-motor stage) to behavior based on refinements of one's own skill (the motor stage). In both stages there is a standard of comparison. In the verbal-motor stage it is called a *memory trace* and with development of higher skill levels it becomes a *perceptual trace*.

Both cybernetic approaches, Bernstein's Model and Adams' closed loop theory, emphasize that conventional S-R models are incomplete because they fail to describe the interaction between the stimulus and the response which actually occurs. In cybernetic models, the learner has a more active role. The nature of the stimulus changes, since it is continuously modified by the learner as the desired standard is approached. These notions are important to teachers because they stress the importance of *knowledge of results* (KR) in mastering any task. To the extent that knowledge of results is immediate, accurate, and meaningful with respect to the desired performance standard, it can be expected to be a powerful stimulus to learning. If these conditions are not met, KR is much less effective in assisting the learning process.

Another factor to consider is the diversity of performance that will be caused by individual differences among students. Assuming that all learners attempt to make their performance identical to the desired standard, there will still be vast differences in learner performance due to different perceptions of what constitutes adequate performance. Just as different thermostats deliver temperature control within a variety of ranges, some narrow and some wide — so do individual learners perform differently if for no other reason than the size of their particular *just noticeable difference* (JND) between desired and performed response. This has two implications for teachers. First, teachers should be sensitive to the possibility that students of equal ability and dedication may perform at different levels due to this phenomenon. And secondly, teachers may be able to concentrate on helping students develop a keener ability to perceive differences between the performance they exhibit and that which is desired. A part of this may come with experience and learning, and part may be derived from clear explanations and directions as the teacher identifies those parts of the activity most important for attention by the learner.

THE FITTS/POSNER MODEL AND ADAMS' CLOSED LOOP THEORY

Although Singer classifies the Fitts/Posner model as a general theory and Adams' closed loop theory as cybernetic in nature, they have in common the perspective that psychomotor learning tends to progress toward responses which are automatic in nature. They hold that activity moves from a stage where every action is consciously and deliberately controlled by the learner to a level where the basic process has become automatic (Magill, 1980). At this point, the conscious activity of the learner can focus upon the feedback from the activity and compare it with the repertoire of past performances. Thus the learner is able to "fine tune" his or her activities and bring them into closer congruence with the desired standard.

For an example, let's get back to our illustration of learning to drive an automobile. The learner is busy concentrating on the placement and operation of the clutch and brake pedal, the accelerator, steering wheel, and turn signals while also monitoring the instruments. It is necessary to orchestrate the simultaneous use of this multitude of controls in a particular sequential and simultaneous fashion. Since it takes a great deal of energy to attend to these activities, it is no wonder that beginning drivers make rather large errors in operation of the vehicle. More than one neophyte has succumbed to what might be called "sensory overload" by forgetting what to do while making a turn. The result might have been bent fenders and a nervous instructor. Later on, when the basic mechanics had been mastered, the learner could automatically perform the activities necessary for making a safe turn, and could therefore concentrate on proper lane placement, appropriate entry speed, and safe merging into the traffic flow. The level of performance was thus more finely adjusted, and a higher level of performance was attained.

The relationships between the levels of cognitive activity are expressed in Figure 3-4. Psychomotor learning occurs in sequence from left to right. As learning increases, the cognitive elements decrease

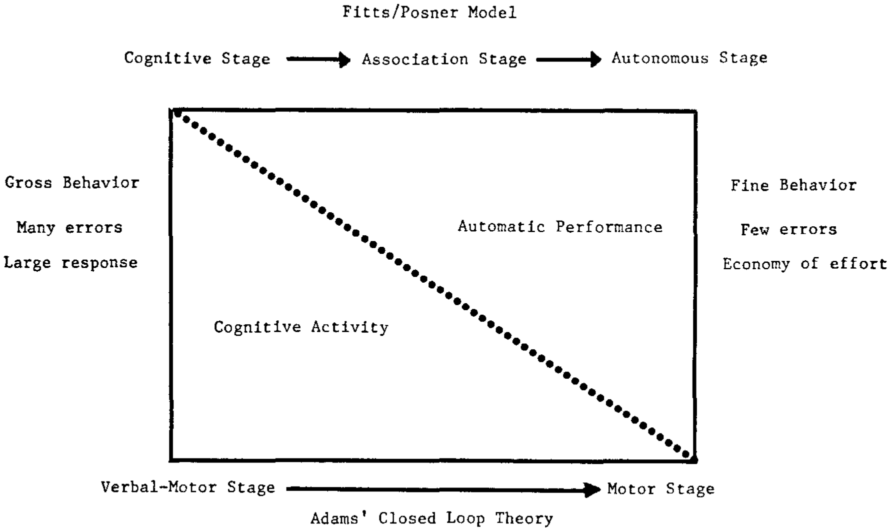

Figure 3-4. Synthesis of the Fitts/Posner model and Adams' closed loop theory of psychomotor learning.

and the automatic increase. The earlier levels of learning are characterized by gross responses, random behavior, and a large response in terms of the amount of activity and number of movements involved. Later efforts show less response, a greater economy of movement, and finer skills. It can be seen, however, that at no time is there a complete absence of cognitive activity; it is only the nature of the cognitive activity which changes.

These concepts are important to industrial educators because they lead us to honor one of the longest held tenets of those who study learning. That is, it is important to keep the steps of the learning activity as small as practical. In this way, the student has time to master the gross mechanics of the task before being expected to produce results which meet high technical standards. This is sometimes a difficult task to accomplish in the industrial arts laboratory. As a well known industrial arts teacher educator observed, students often "... aren't interested in the psychomotor skill of using a hacksaw blade — they just want to cut the damn tailpipe off."

IMPLICATIONS OF THE PSYCHOMOTOR LEARNING THEORIES FOR INDUSTRIAL ARTS TEACHERS

As we have seen, the various theoretical approaches attempt to explain different aspects of human psychomotor learning. Each of these theories has different values to the researcher and to the practitioner. Some may be specific and limited in scope to an extent desirable by researchers who seek to observe cause and effect relationships and to design experimental studies. Therein lies their value to the profession, for it is through research that basic truths are identified and explained. However, to the extent that psychomotor learning theories are successful in generating researchable questions, they may be limited in value to the practitioner.

The teacher needs a set of practical guiding principles and strategies that will assist in the design and implementation of instruction. The instructor or teacher seeks to generalize across theories for workable solutions to everyday problems, and it is the teacher educator's responsibility to assist in this. To the extent this goal is realized, the broad descriptive scheme may not be of much value for stimulating research and experimentation. Singer is quite correct to make this distinction in the previous chapter and to indicate that Gentile's model tends to be most helpful to research. Since this observer would like to draw some conclusions about the merit, value, goodness and worth of the various theories as they affect the teaching of industrial arts, they will be discussed in terms of their implications for teachers and for teacher educators.

Another important aspect of these theories, and one which should not be forgotten, is their interrelatedness. To some degree, each approach contains elements of the others. No single theory or model is really a pure, unique, or discrete approach. In the language of the statistician, they are not *orthogonal* (unrelated) — they do in fact blend into each other. This might be a serious problem to the purist who wishes to identify clear and uncomplicated theoretical bases for psychomotor learning, but it should not be a problem to our profession. In fact, the very relatedness of the approaches helps make the case for generalizable principles which may be of use to industrial arts teachers and teacher educators.

PERSPECTIVES ON PSYCHOMOTOR LEARNING

With these concepts in mind, then, the following general perspectives are offered as a distillate of current psychomotor learning thought which may be of value to teachers and practitioners. Most of them are drawn from three sources:

1. A synthesis of the theoretical approaches described by Singer with basic learning theory as described by O'Neil (1978) and Tighe (1982),
2. the recommendations of Drowatzky (1981) and Magill (1980), and Stallings (1982) for enhancing motor learning, and
3. the observer's personal interpretations based upon observation and experience.

1. *Classification of Motor Skills.* Motor skills can be classified into several categories on the basis of several skill characteristics (e.g., open-closed, gross-fine, continuous-discrete). For instructional purposes it may be useful to analyze motor tasks in terms of the type of skill which is involved, since the evidence available to us indicates they may be learned (and should therefore be taught) differently. For closed skills the teacher should provide conditions as close as possible to the conditions under which the act will be performed. This will enable the student to learn a set of skills which are highly transferable to the situation in which they will be used. For open skills, the conditions of practice should be systematically varied so that the learner is able to program more or less appropriate responses to each set of circumstances which may be encountered. Fine motor skills should be developed by successive approximations, with the learner first getting the general idea of the response, then fine tuning the response to specifications. If one may be permitted an analogy, continuous motor skills appear to be to open skills as discrete skills are to closed skills. They may then be responsive to similar instructional treatments.

2. *Observation of Behavior.* Because learning is not directly observable, it must be indirectly inferred from behavior. The instructor should take care to insure that the behavior demonstrated by the student actually reflects the desired learning by remembering two important points: (1) genetic and physical endowment as well as nutrition and other factors can influence initial performance out of proportion to the incidence of learning, and (2) some sort of pretest or baseline data should be established to facilitate evaluation of the learning that has taken place instead of just the performance.
3. *Perceptual Changes with Learning.* With increasing experience, the aspect of the stimulus upon which the learner focuses attention can be expected to change. Early on, the physical position of an object may be important to the learner while as skill develops the movement or change of movement by the object may become significant. The instructor should be sensitive to this tendency and be prepared to give appropriate cues and feedback at each level of skill development. If the correct focus of concentration can be identified, the teacher's feedback will make sense in terms of the learner's perception and will enhance learning and motivation.
4. *Self-Pacing.* Each individual has a unique rate or speed of performance which minimizes errors and physiological inefficiency and maximizes the value of experience. Such self-pacing of activities may enhance learning of psychomotor tasks, especially when they are complex in nature and the learner is at an early stage of skill development.
5. *Learning Curves.* When plotting the development of any skill building task, we derive learning curves. These curves show up as a series of ascending scallops, separated by flat plateaus. It is important to note that all learning tasks will show segments of rapid learning followed by plateaus, which are in turn followed by later jumps in learning. The teacher of industrial arts should be aware that this is expected to occur, and should not be discouraged when it does.
6. *Knowledge of Results (KR).* We know several things about knowledge of results and its relationship to psychomotor learning. One of the most important is that KR is an environmental variable and as such is under direct control of the teacher. It has three primary functions: (1) transmitting information, (2) enhancing motivation, and (3) providing reinforcement to the learner. As an external feedback source, it seems to be more important during the early stages of learning a psychomotor skill, while later on it is not so necessary for maintaining performance at a desired level. When it is given, KR must be precise about the areas of success or failure enjoyed by the individual in performance of the task. But teachers should not subject the learner to information overload — only pro-

vide as much information as the individual is capable of handling at a given time. They should also provide the learner with enough time to process or synthesize the KR information so it can be integrated into the next performance. With regard to the timing or placement of KR, research appears to indicate that the nature of KR given to the learner is more important than its timing. Thus, appropriate knowledge of results that is within the learner's frame of reference, even if given late, is better than inappropriate or faulty KR given immediately.

7. *Feedback.* This is a different concept than KR and is not necessarily under the direct control of the instructor. However, it always occurs in some way with every activity, and it is one thing that can be influenced by the instructor. The research evidence indicates that it operates differently in the learning of closed skills than in open skills. For open skills, where environmental stimulation is not so important, the feedback is proprioceptive in nature. A small time lapse between the activity and feedback may be desirable, but in any case the learner needs to know when it "feels right." On the other hand, closed skills are closely tied to outside feedback, including artificial cues. Here, it is important that the cues relate clearly and accurately to specifications of the task, since the accuracy of performance is related to the accuracy of feedback.
8. *The Generalized Motor Ability Theory.* Research has shown pretty clearly that there is probably no such thing as a generalized psychomotor ability. In all probability, the all-around athlete has a happy combination of specific skills which may apply over several areas. Teachers need to be aware of these individual differences, and not place too much faith in overall psychomotor ability tests as general predictors of psychomotor learning.
9. *The Transfer of Learning Skills.* Teachers are concerned with the appropriate transfer of learning skills in students. They often wish to impart general skills which will be useful to the students in a variety of situations. Transfer can be negative as well as positive, and it is normally in our interest to avoid negative transfer of learning. The results of research show that, in general, the more nearly identical the tasks, the more easily will the transfer occur.

   Another finding is that the kind of transfer we can expect may be related to the concepts of task complexity and task organization. Task complexity refers to the degree of combining or folding of parts and subparts into an activity, and the interlacing of those parts with continuous modification, fine tuning, and decision making in order to complete the activity. Task organization is the degree to which the task or activity is arranged into a coherent whole such that once perfected, the performance occurs rather cleanly and repetitively, without continuous adjustment. While the research results are not conclusive, they suggest that for some skills, presentation of the whole task to be learned is better for transfer, while for others the parts should be presented first, then the whole concept. The "whole" method is difficult-to-easy because it goes from the whole to the parts, while the part approach is easy-to-difficult since the small parts are learned first. Swimming and volleyball, for example, may require skills that are different in terms of complexity and organization. While swimming is a relatively "organized" and simple activity, volleyball is a more complex activity which is not "organized" in the same sense as swimming. If these skills are plotted (as in Figure 3-5), it can be seen that when task complexity is high and task organization low (as in volleyball), the easy-to-difficult practice model (position A) should be more rewarding. Conversely, the relatively low complexity/high organization task (swimming) would call for difficult-to-easy practice, as indicated in position B.

Another dimension of learning transfer is known as bilateral transfer, in which ability existing in a preferred limb (the dominant one) may be transferred to the less favored one. We can help

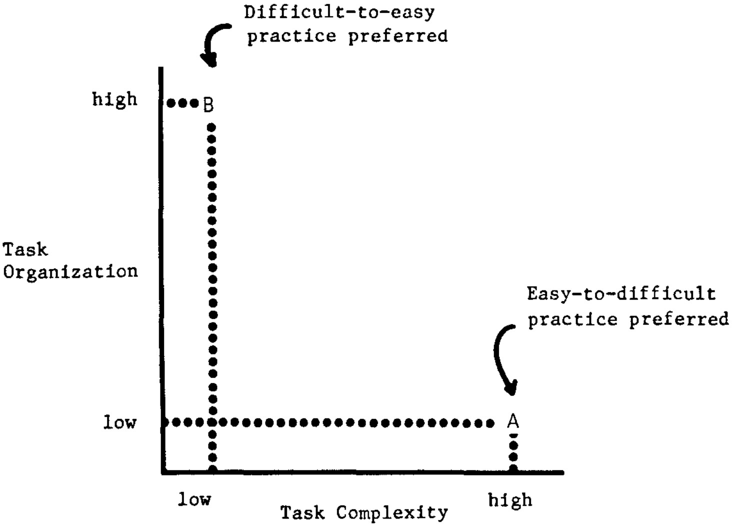

Figure 3-5. A prescriptive task organization/task complexity decision model for facilitating transfer in psychomotor learning.

achieve bilateral transfer of psychomotor skills by initiating early practice and helping to develop cognitive understanding of the skill while using the preferred limb.

Some excellent techniques for facilitating desirable skill transfer were noted by Ellis (1965), and reported by Magill (1980). They are summarized here, with examples drawn from industrial arts experience:

a) *Maximize the similarity between teaching and the ultimate testing situation.* For us, this means that we should use facilities and equipment similar to that which will be used by our students. Industrial arts teachers, for example, should be trained on equipment similar to that which they will likely encounter in the field. Obviously, they may find that in the real world they are using obsolescent or obsolete equipment in a shop which is less suitable than expected. Teachers should therefore be educated on equipment which does the best job of interpreting technology or technology systems, and they should receive sufficient and effective preparation that will allow them to adapt the equipment they find to the new system and content of industrial arts. In the larger sense, they should also be given the related skills of public relations to accomplish needed curriculum and equipment change.

b) *Provide adequate experience with the original task.* Teachers should use lead-up activities to learning tasks when possible. Measurement games, for example, might be used in preparation for teaching measuring skills with a tape or a ruler. The games teach the measurement concepts to be used before introducing the psychomotor component of the activity.

c) *Provide a variety of examples when teaching concepts and principles.* The use of a particular tool or device or material should be described in terms of its function, and then students should be allowed to use it in different ways to produce the same or different products.

d) *Label or identify important features of a task.* This is equivalent to using an outline, or giving students a set of performance objective statements. As a wise veteran teacher once said to me, "Tell them what you're going to tell them, then tell them, then tell them what you told them!"

e) *Make sure that general principles are understood before expecting much transfer.* Try to ensure a fairly high standard of performance at psychomotor skill tasks before allowing students to transfer skills. This is especially important for open loop skills, which tend to become fixed and automatic.

Another technique to enhance transfer of psychomotor skills is the formative evaluation opportunity which occurs throughout the learning sequence (Erickson and Wentling, 1976). In formative evaluation the instructor as a manager of learning carefully observes the progress of the student toward the desired objectives, diagnoses problems or difficulties as the student experiences them, and prescribes appropriate experiences for the student which will maximize learning. As the student's skill level increases, the behavior is shaped by the instructor until it is a very close approximation of the desired results. In this way, students receive the guidance they need to make the best use of the time available to them for learning psychomotor skills. An appropriate system of formative evaluation will go a long way toward enhancing the learning of psychomotor tasks in terms of perceptual changes with learning, self-pacing of learning, knowledge of results, feedback, transfer of learning, and memory for long-term retention of psychomotor skills.

10. *Perception.* The information used in psychomotor skill performance is gained through a variety of sensory apparatus, is processed in some way, and is stored for a short length of time. Accuracy of perception is obviously tied to accuracy of interpretation, processing, and response. Therefore, student perception is a concern for the teacher. In dealing with this problem, teachers should know that there do not appear to be generalized perceptual abilities — they are highly specific to perceptual area or even the body part involved. However, some seem more important than others. Visual perception tends to be associated with superior performers in terms of depth perception, peripheral vision, and speed of interpretation. Peripheral and subtle visual cues tend to become more important as skill level increases; this may also be true for other perceptual domains.

    Two other considerations seem important for teachers. First, psychomotor perception memory tends to remain stored for only a second or two. This makes continuous attention necessary for the anticipatory timing so essential to many psychomotor tasks. Our instructional prescription, especially in a task with a changing environment, would be to see that the student focuses attention upon the stimulus as early as possible and for as long as possible. In this way, earlier learnings and associations may be used in directing the behavior. Secondly, the issue of integrating visual, proprioceptive, and kinesthetic perception is a difficult one, and seems to depend upon the level of learning to be taught. It is probably safe to say that while vision is important early in learning and kinesthetic perception at later stages, at no time is kinesthetic or proprioceptive perception alone very satisfactory for the acquisition of new learning.

11. *Memory and Forgetting.* There is a vast body of research on the issue of remembering and forgetting. Many parameters have been studied in terms of how they affect memory. A few are important with reference to the theories of psychomotor learning. First, memory involves the coding, storage, processing and retrieval of information in either a short-term or long-term mode. Motor memory seems to be analogous to verbal memory and to follow pretty much the same rules. It has a very limited life span in the short-term mode, and can only handle about 7-9 movements. The teacher's task is to enhance long-term psychomotor memory in instances where that is desirable. This may be accomplished by multiple rehearsals of the memory, and by helping the learner "process" the memory at a deeper level. Obviously, the better organized in prerequisite order the tasks are and the more sense they make to the learner, the easier it will be to accomplish this.

    The second consideration involves the presentation of serial information (or tasks), and the ease with which the tasks are learned. Learners appear to exhibit a typical learning behavior when presented with a serial learning task. They tend to remember the first few items in the sequence and the last few fairly well, while having trouble with the middle elements. This supports the views of many information processing theorists that if tasks are presented in small bits and then put together, learning will be enhanced. If this is not possible, our practice should be to emphasize and reemphasize the *middle* portion of sequential motor behavior so that student memory of those sectors will be enhanced.

CONCLUSION

The various theories of psychomotor learning are of value to industrial arts teachers and practitioners because they provide perspectives on the dynamics of the learning sequence. While each theory tends to have its own focus and perhaps parochial interest, there are useful commonalities and overlaps between them. Often, the theoretical approaches are more successful in explaining one segment or dimension of psychomotor learning in humans than in explaining the entire range of psychomotor learning behavior. These approaches are good for experimentation but not so useful to teachers. Other approaches generalize applications for teachers. They are not so useful to researchers. This chapter has attempted to strike a balance between the two approaches and to extract knowledges and principles from them which would be of value to industrial arts teachers and teacher educators. These bits and pieces may seem to be somewhat disjointed at times; but, alas, that is a reflection of the state of our knowledge.

As the state of the art is advanced by researchers, perhaps a unified theory will emerge to explain the vast majority of psychomotor learning behavior. This is intuitively appealing because it would seem to be a convenient way to approach the subject. However, because of the wide range and unique character of psychomotor skills, and the vast diversity of tasks to which those skills may be applied, our knowledge will probably continue to be segmented. Be that as it may, industrial arts education teachers still have the benefit of useful knowledge and techniques that work, and can be applied to local instructional situations no matter what the source. Let us hope that good use can be made of them.

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Chapter 4

Development of Perceptual-Motor Abilities

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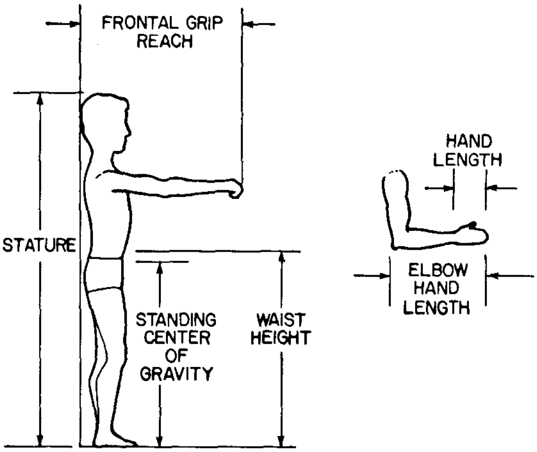
Perceptual-motor development is the person's ability to obtain information from the environment; analyze the information; decide when, how, and what action to take; and then execute that action (Williams, 1983, p. 9). The development of perceptual-motor functioning is inextricably linked to growth in physical and intellectual ability and is directly related to experience in performing similar motor tasks.

Professionals from many fields have studied perceptual-motor development for a variety of reasons. A major purpose of this chapter is to identify information from these sources which will be beneficial to industrial arts educators. First, selected anthropometric data are presented to emphasize the tremendous difference in physical growth which is found among school age children. Following this information, four models which have been developed to assist in the understanding of perceptual-motor development will be presented. The perceptual-motor development factors from these models which are of greatest interest to industrial arts educators will be explained in some detail. In addition, selected research findings will be presented in an effort to further define the factors which affect motor performance. Finally, a summary which focuses on the significance of the models and research data for industrial arts education will be presented.

ANTHROPOMETRIC DATA

The tremendous differences in physical size of children within a given age group is an important consideration in assessing perceptual-motor development. In a study conducted for the U.S. Department of Commerce [1977], measurements of body elements of males and females ages 2 through 14 were summarized. A small sample of these

Table 4-1
Selected Anthropometric Data for 11-14 Year Old Youths



Dimension	Mean	Min	Max	N
Weight [Kg]	43.48	20.7	85.8	1155
[lbs.]	95.9	45.6	189.2	
Stature [cm]	151.69	122.0	183.2	1155
[in.]	59.7	48.0	72.1	
Frontal Grip Reach [cm]	63.36	51.7	78.1	362
[in.]	24.9	20.4	30.8	
Waist Height [cm]	91.70	72.8	113.7	381
[in.]	36.1	28.7	44.8	
Standing Center of Gravity [cm]	86.14	74.8	101.3	241
[in.]	33.9	29.4	39.9	
Elbow-hand Length [cm]	40.74	32.2	51.7	1150
[in.]	16.0	12.7	20.4	
Hand Length [cm]	16.57	13.2	21.7	1149
[in.]	6.5	5.2	8.5	
Grip Strength [Kg]	39.36	12.0	89.0	814
[sum of right and left hands] [lbs.]	88.2	26.9	199.4	

data are presented in Table 4-1 for the age group typically found in middle or junior high schools. Give special attention to the minimum and maximum quantities for each dimension. A weight difference of 65 kg (143 lbs.) between the smallest and largest children and a hand length dimension which varies by 7.5 cm (2-7/8 in.) is sufficient to indicate the need to consider physical size an important factor in the development of motor skills.

Low center of gravity of a given child may prohibit that child from performing tasks which require the application of horizontal force at a height of five feet. Tool operations which require long, smooth movements may be impossible if arm length is insufficient. These examples suggest that physical size may be seen as limiting a person's ability to perform selected tasks. This point will become more clear as the models of perceptual-motor development are presented.

PERCEPTUAL-MOTOR DEVELOPMENT IN CHILDREN

Gallahue (1982) presents a model of physical and mechanical factors affecting the development of movement abilities. The principal elements of this model are shown in Figure 4-1. The mechanical factors identified by Gallahue are stability, giving force, and receiving force. Stability (balance) is further explained as being related to the center of gravity, base of support and line of gravity. Motor tasks such as standing and sitting require that the center of gravity remain stationary, while lifting and digging tasks require that the body center

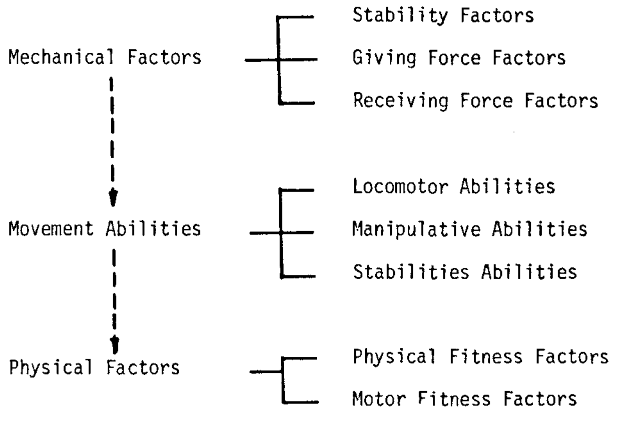


Figure 4-1. Physical and mechanical factors affect the development of movement abilities at all phases of motor development.

of gravity be in continual motion. This later type of activity is classified as a dynamic balance movement and requires a more advanced level of control.

"Base of support" refers to that part of the body which is in contact with the floor or other supporting surface. When standing, the base of support can be altered by the distance the feet are separated. The relationship of the center of gravity to the base of support is described as the line of gravity. This is a vertical line passing through the center of gravity. If this line falls outside the base of support the person will topple.

The second major sub-category of mechanical factors is "giving force." Force is required to initiate, accelerate, and decelerate movement. This factor is related to the position of the body relative to the direction that the force must be applied. By taking maximum advantage of center of gravity and skeletal structure of the body, the maximum force can be applied with the least energy. When an individual attempts to push a heavy object, leaning forward makes the task easier because the weight of the body acts to help move the object and the leg muscles can apply the needed force through a movement similar to walking.

The mechanical factor "receiving force" suggest that if an individual must resist or stop a moving object it is desirable that the force be absorbed over as great a distance as possible. The old practice of moving heavy materials such as stone or brick by forming a human chain and throwing the stone or brick from one person to the next will serve to illustrate the desirability of absorbing force over as long a distance as possible. If the persons hold their hands in a fixed position and allow the stone or brick to impact the hand, considerable damage is sure to occur. It would be impossible to stop the moving object immediately and excessive amounts of energy would be expended by the attempt. Allowing the arms to move with the brick as it is caught enables the brick to be decelerated more slowly and with less effort. It is also important that the area of the body to which the force is applied be as large as possible thus reducing the amount of force applied per square inch of body surface.

Gallahue's model identifies two types of physical factors which affect movement abilities. Physical fitness describes the individual's general state of health which is directly related to a person's ability to perform routine, daily tasks without undue stress. Muscular strength, muscular endurance, circulatory-respiratory endurance, and muscular flexibility are commonly considered to be the components of physical fitness.

Motor fitness has to do with those special abilities necessary to perform a given task at a high degree of proficiency. According to Gallahue, these factors are speed, agility, coordination, balance, and power.

The terms used by Gallahue and much of the research used to support the above model are from the field of physical education. Also, considerable emphasis is given to young children. For these reasons, it is necessary to consider that the factors mentioned may not have the same importance when applied to skills which involve tool utilization. However, it is apparent that the basic ideas have face validity and are helpful as one considers the factors which are important to perceptual-motor development.

According to Williams (1983), four basic categories of behaviors can be identified that are foundational. These are: (1) gross motor control; (2) fine motor control; (3) simple auditory, visual, and tactile-kinesthetic behaviors; and (4) body awareness. Williams claims that these four foundational behaviors are essential for subsequent higher-order development.

Gross motor control is achieved when movement tasks such as walking, running, skipping, and hopping requiring the use of large muscles have been mastered. Fine motor control is defined to mean control over individual body parts such as the hands and fingers in precisely manipulating small objects.

The foundational auditory, visual, and tactile-kinesthetic behaviors enable the person to detect, recognize, discriminate, and interpret stimuli received through the senses. Body awareness relates to one's ability to recognize, identify, and differentiate the parts, dimensions, positions, movements, and spatial location of the body (Williams, 1983, p. 23).

Williams' work focuses on early childhood and does little to explain advanced levels of perceptual-motor development. However, the four foundational factors identified are helpful in analyzing the development of a given individual relative to the requirements of a given task. The third and fourth categories suggest considerable opportunity for developing instructional procedures which will assist learners to attend to the appropriate questions while they are learning new tasks.

NEUROPSYCHOLOGICAL MODEL OF PERCEPTUAL-MOTOR DEVELOPMENT

The neuropsychological model developed by Sage (1977) is based on general systems theory and states that inputs in the form of stimuli are received by the sense organs. These inputs are transmitted to the brain and spinal cord for decision making (processing). The commands (decisions) are transmitted to the muscles and glands to produce movement as an output. Finally, feedback through the sense organs

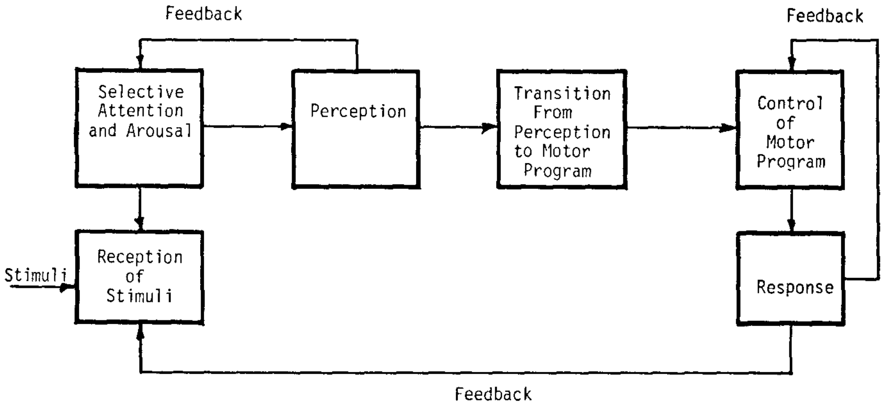


Figure 4-2. A model of the functional and neural mechanisms for motor behaviors.

becomes input for the next cycle of processing. Sage has expanded this model and provides a detailed explanation of each section which will be briefly reviewed below. Figure 4-2 depicts the key concepts and relationships shown in this model.

Beginning with internal and external stimuli as inputs received by the sense organs, information is attended to selectively. The human brain is simply incapable of reacting to all the stimuli received. Therefore, it is important that only relevant stimuli receive attention. Eight factors have been found which correlate with attention. These factors are: (1) intensity, (2) novelty, (3) set, (4) motivation, (5) expectancy, (6) experience, (7) ongoing sensory information, and (8) demands of the task. Many of these factors have a developmental component. Special needs students may perform well below the norm for their age level because they have not yet developed the needed capacity for attending to the task. One or more of the eight factors may be varied in an effort to improve a student's performance.

Experience with similar tasks assists the individual to recognize significant stimuli because the individual knows what to expect, has the appropriate set, is familiar with the ongoing sensory information which will be received, and is familiar with the general demands of the task. In addition, very few if any of the stimuli will seem novel because they will have been previously experienced. An individual without previous experience performing similar tasks will attempt to respond to irrelevant stimuli because of the inability to discriminate.

Selective attention is a function of one's state of arousal or state of alertness. Two different types of arousal can be identified. Background level arousal is the general state of arousal which varies for different individuals depending on such factors as time of the day, state of health, and amount of rest received. Stimulus-specific arousal is triggered by novel or changing stimuli. Increasing arousal generally increases ability to perform; however, very high levels of arousal may cause disorganization of behavior and a reduction in the quality of performance. Thus, the concept of optimum level of arousal has gained considerable attention and support in research (Sage, 1977, p. 196). A fairly simple example of the concept of the effects of arousal will serve to illustrate the importance of this concept to industrial arts education. A highly skilled student who lacks sufficient rest and/or is distracted by personal problems is unlikely to perform even routine tasks satisfactorily. If the arousal level can be increased through motivation techniques then the student may be expected to perform at a satisfactory level in spite of the problems he/she may have. If some emergency occurs during the performance of the tasks which requires that the task be performed very rapidly, excessive arousal may occur. While the student may be highly motivated and want to perform the task successfully, it is very likely that the quality of the performance will decrease due to the increased arousal level. Thus, effective performance can only be expected when the state of arousal is consistent with the needs of the task.

The process of perception includes obtaining, organizing, integrating, and interpreting information about the task to produce meaning from the incoming data. Perception depends upon the abilities of: (1) detection, (2) discrimination, (3) recognition, and (4) identification. These abilities must be developed before accurate perceptions can be rapidly formed thus enabling efficient motor performance to be exercised.

It is known that perceptual abilities vary among and within individuals. Individuals have different primary modes of perception. Some prefer visual; others find auditory or kinesthetic more helpful. Considerable evidence exists to suggest that the preferable type of stimuli varies with the task and the degree of proficiency or skill which the individual has achieved in performing the task. For example, kinesthetic information becomes more important in the performance of tasks involving the use of tools as the individual becomes more skilled. A beginning student consciously thinks about each movement when learning to turn objects on a wood lathe. As the student's skill level increases, these conscious movements become more automatic because information regarding the position and movement of the body elements is transmitted directly to the brain through the central nervous system in a process known as kinesthetics. This means that the conscious thought processes are no longer needed for efficient performance of the task.

The balance of the model presented by Sage focuses on the mental processing which results in movements or behaviors being executed. From a development perspective, two factors deserve special attention. First, past experience may enhance or limit an individual's ability to select an appropriate motor program. Second, physical limitations must be considered both in the development and execution of the motor program.

Models such as the one developed by Sage provide an interesting tool for considering the functioning of the brain; however, casual attention to such a model may fail to reveal the dynamic environment in which the central nervous system must function. The multiplicity of stimuli received through the senses instantaneously is considerable. However, when the time period is extended it is easy to understand how the perception process can become confused and result in poor performance because of information overload.

TAXONOMY OF HUMAN PERCEPTUAL-MOTOR ABILITY

Much research has been conducted about perceptual-motor abilities in relationship to specialized military tasks such as flying airplanes. While this research was conducted primarily with young adults, the findings are of considerable significance and deserve the attention of educators who are concerned with the perceptual-motor development of secondary school youth and young adults. Fleishman used factor analysis techniques to identify eleven perceptual-motor factors and nine physical proficiency factors which account for the common variance in the ability to perform such tasks. Because many of these factors directly relate to tool manipulation, they will be presented and briefly described (Fleishman, 1972).

The eleven perceptual-motor factors are:

1. Multilimb coordination: ability to coordinate the simultaneous movement of limbs to operate controls.
2. Control precision: precise adjustments of large muscle groups when operating controls.
3. Response orientation: ability to rapidly select and correctly move controls.
4. Reaction time: speed with which the person is able to respond.

5. Speed of arm movement: ability to move the arm quickly without concern for accuracy of the movement.
6. Rate control: ability to respond to changes in speed and direction of a continuously moving object.
7. Manual dexterity: ability to manipulate fairly large objects with the arm-hand movements under conditions which require speed.
8. Finger dexterity: ability to use the fingers to manipulate small objects.
9. Arm-hand steadiness: ability to precisely position the arm-hand in movements where speed and strength are minimized.
10. Wrist, finger speed: ability to move the wrist and fingers rapidly.
11. Aiming: ability to rapidly mark a dot within each of a series of small circles.

Tests have been derived to assess the individual's performance on each of these factors. In addition, tasks or jobs may be analyzed to obtain identifiable levels of performance for each of these factors. Binary decision flow diagrams have been developed to ascertain the perceptual-motor abilities relevant to a task or job (Fleishman, 1970). This enables the educator to match the task to the measured ability level of the individual. Further information on the topic of assessing aptitudes may be found in Chapter 5.

Little is known about the development of these eleven perceptual-motor factors. The degree to which each of these factors may be taught/learned has not been researched. It is entirely possible that appropriate and timely training could add significantly to an individual's ultimate performance. From a developmental perspective, it would be interesting to know how the superior performers acquired the specific ability and what limited the ability of those individuals who performed at lower levels of proficiency. It may be that carefully planned industrial arts laboratory activities have a significant impact on the development of these factors. If this is true, industrial arts educators could demonstrate that these activities make an important contribution to the perceptual-motor development of their students.

In addition to the eleven perceptual-motor factors, Fleishman and his colleagues have identified nine physical proficiencies which relate directly to gross physical performance. By studying these factors it is possible to identify the specific requirements of a task more precisely (Fleishman, 1972). The nine physical proficiences identified are:

1. Static strength: maximum force an individual can exert.
2. Dynamic strength: ability to exert force repeatedly or continuously over time.
3. Explosive strength: ability to apply force instantaneously.
4. Trunk strength: dynamic strength of trunk muscles.

5. Extent flexibility: ability to flex or stretch trunk and back muscles.
6. Dynamic flexibility: ability to make repeated, rapid, flexing trunk movements.
7. Gross body coordination: ability to coordinate action of several parts of the body while the body is in motion.
8. Gross body equilibrium: ability to maintain balance without visual cues.
9. Stamina: capacity to sustain maximum effort which requires cardiovascular exertion.

The nine physical proficiencies are subject to improvement through appropriate exercise. However, each individual will be limited by his physique to some maximum development of each of these proficiencies.

Fuzak (1958) conducted one of the earliest studies in industrial arts of the relationship between physical maturation and the ability of boys to perform complex finger coordinative activities. The findings and conclusions of his work are as important today as they were in 1958 and should be used to guide the selection of activities which we expect youth to perform. Fuzak reported that "the level of physical maturity attained by a junior high school boy determines the level of his ability to perform complex finger coordinative activities" (p. 78). He found that grip strength as measured by a hand dynamometer is an effective indicator of the level of physical maturity. "Junior high school boys falling below 24 kilograms in a mean dynamometer score, should not be expected to perform activities in industrial arts requiring complex finger coordination. Further, such activities should be carefully selected and limited for boys with a grip strength below 28 kg." (p. 79).

Fuzak made the following statement regarding the implications of his research:

> The junior high school industrial arts teacher should screen possible learning activities, so that those planned at earlier grade levels concentrate on large muscle coordinations, rather than upon complex finger coordination.
>
> Implications of a similar sort affect many portions of the junior high school program, where complex finger coordinative activities are carried on. Attention should be given by these teachers to the physical readiness of their pupils to satisfactorily engage in the learning experience provided. Many pupils are driven away from learning activities involving complex finger coordinations, because of their lack of physical readiness to perform them satisfactorily. Much of the time and effort they expend is wasted. This is probably true in particular of the more intelligent pupils. Many of them are

> *somewhat accelerated in school, while duller pupils are somewhat retarded. This must be a deep concern of all teachers who teach activities requiring complex finger coordinations. (pp. 80-81)*

Given the nature of many industrial arts laboratory activities, there should be no doubt that our programs make some contribution to the physical proficiency of our students. However, the extent of these contributions has not been documented. Perhaps, a more important question relates to the demands our programs make on students. We know very little about the perceptual-motor or the physical proficiency factor requirements of the tasks we expect our students to master. Possibly, we are introducing tasks which are inappropriate to the development of the individual either because they exceed or fail to make adequate use of the individual's abilities. The importance of this question is enhanced by the addition of female and special needs students to industrial arts classes because these students tend to extend the range of abilities found in a typical class.

Figure 4-3 is an attempt to summarize developmental characteristics of children and suggest appropriate industrial arts activities (Rosser, 1978). The ages identified with each set of characteristics are only intended to suggest a sequence of development and should not be seen as lines of demarcation. The characteristics of technological activities identified in the table have not been subjected to rigorous research but they do seem to be consistent with what is known about perceptual-motor development.

Another attempt to assist educators in their efforts to select appropriate activities for young children was reported by Babcock et al. By reviewing the experiences of a large number of elementary teachers and the industrial arts consultants working in the Great Neck, New York schools, appropriate expectations for the use of selected hand tools have been described by grade level, Figure 4-4.

(See next three pages)

Figure 4-3. Developmental characteristics and appropriate technological activities for children ages 3-13. NOTE: From "The developmental growth of elementary school students and the role of industrial arts in the process" by A. Rosser, 1978, pp. 33-35. American Council for Elementary School Industrial Arts.

4-3 (continued)

DEVELOPMENTAL CHARACTERISTICS				Characteristics of Appropriate Technological Activities
Age	**Physical**	**Emotional/Social**	**Motor and Intellectual**	
3	Very rapid growth Self sufficient in eating Disposition indicates need for rest Toilet trained	Cooperative, happy Can share and take turn Peaceful with peers Needs attention and praise Imaginary friends Can be reasoned with	Can alternate feet going upstairs Rides three wheeled toys Spills at meal time are less frequent Throws overhead with body Able to draw recognizable shapes Can stand on one foot	Creative products as desired by children Sawing, nailing, drilling, and gluing are desirable activities Red clay with pinch pot and slab work Activities should stress large muscle development Jigs and fixtures will be needed to help guide tools e.g. miter box, drilling guide Materials such as corrugated cardboard, foamed plastic sheet, and thin, narrow strips of wood should be on hand Odd shaped, small piece of scrap lumber may be used for wood sculpture A large log, railroad tie, or fence post provides an excellent place for driving 4d or smaller common nails
4	Very energetic Can run, turn, and stop without falling Dramatic play Improved dexterity Reality-oriented Large muscle use predominate	Begins bossing, arguing, boasting and even fighting Home oriented Will become engrossed in individual activity Interest in sexual differences	Preoperational thinker No longer need to give full attention to common motor activities More thinking about what is being done — less about how-to-do-it	
5	Reduced rate of growth Legs lengthen in greater proportion Large muscles developing faster than small	Ready to engage in quiet activity Likes to be creative in constructing things to take home	Activities involving fine or close work should be avoided Enjoy block and plank construction Able to visualize things	
6	Growth rate reduced Body type becomes evident Hand-eye coordination continue to improve Large muscle skill more smoothly executed Fine motor skills need refinement Handedness established	May become stubborn, quarrelsome, and selfish More compatible with parent of opposite sex May identify with adults Likely to become dependent Can play in organized team	Motor interest tend to be the same as 5 year olds. They are executed with more skill Increased attention span and ability to concentrate Differentiate between reality and fantasy Great curiosity	

4-3 (continued)

DEVELOPMENTAL CHARACTERISTICS				Characteristics of Appropriate Technological Activities
Age	**Physical**	**Emotional/Social**	**Motor and Intellectual**	
7	One of the most active periods in the childs development Becomes absorbed in games which involve running, jumping, chasing, or dodging Like wheel toys	Like small group play Behavior alternates between extremes of good and bad High regard for the opinion of teachers	Vocabulary is important to 7 year olds Theirs contains about 2600 words Knows money Knows name of parents and address Begins reading	Use of small size regular tools becomes easier Products can be preplanned Jigs and fixtures are necessary to provide the desired accuracy Simple group projects can be useful Technological activities can be related to academic subjects to provide concrete experiences which are meaningful to this age child Cost of materials and the time required to do the work can be considered Some children will begin to develop hobby interest which will overlap school activities
8	Show regular growth Nervous habits may develop Hop scotch and jumping rope are popular	Begins to be influenced by peers Choice of friends not influenced by economics	Not able to construct things as well as desired Can tell time Understands basic math	
9	Fine motor development evident Writing improves Enjoys bicycling, swimming and skating	Signs of modesty Not good group member Respects property rights Behavior often better away from home	Able to handle multiplication and division Reduced interest in fantasy Special interest begin to replace totally play activities	
10	Slowed in growth Begins to be concerned about physical appearance Active Likes all types of play Adventuresome	Antagonism develops between the sexes Many students begin lifetime hobbies Works well in groups Eager to learn new skills and work with adults	Thinking in the concrete operational stage Begins to show interest in the past Can handle money May become a perfectionist Interested in tools, skills, occupations, and products of the real world	

DEVELOPMENTAL CHARACTERISTICS				Characteristics of Appropriate Technological Activities
Age	Physical	Emotional/Social	Motor and Intellectual	
11	Girls show rapid increase in weight and maturity Boys more active Both willing to work to learn new skills	Will play games as team member Privacy becomes an issue	Begins to plan ahead Interested in thoughts of others Enjoys gathering facts and presenting a case	Fine motor skills can be used effectively Strength much less a factor in choosing tools and materials Students will be more interested in planning activities They will be more responsible in obtaining materials, tools, and supplies Technological activities could relate to other areas of the curriculum
12	Many girls no longer equal to boys in strength Most children begin to exhibit individual preference for games and motor skills	Club memberships take on new meaning Team games become important	Critical of their own efforts Interested in earning money	
13	Less involved with games which require whole body activities Some children are awkward Most girls are aware of their developing figures	Social contacts widening Will want some privacy	Ability to reason sharpens Can deal with abstract ideas Can control emotional outburst Difficult age for parents and teachers	

GRADE	K-1	2-4	5-6
USE OF "C" CLAMPS	Can be used successfully at all grade levels with a minimum of instruction Useful for holding material for nailing, filing, sawing, or sanding — may often be used in lieu of a vise.		
USE OF HAMMER	Insufficient muscle and eye-hand development to use correctly. Hold hammer near head and depend on weight. Great difficulty holding nails smaller than 1".	Have some difficulty pulling nails properly. Muscular control improves — some begin holding hammer properly.	Children can successfully use 13 ounce hammer. Can use hammer to pull nails properly.
USE OF COPING SAW	Few can be taught to replace blades. Good for small, thin pieces of wood. Teacher will have to help install blade.	Still have difficulty cutting at right angles to face of wood.	Learn to twist blade and use saw for piercing work. Impossible to saw straight line.
USE OF COMBINATION SLIP JOINT PLIERS	Can be used for bending wires and similar uses.	Has strength enough to cut stove pipe wire with pliers	Should be aware that pliers are not used where a wrench is needed.
USE OF TRY SQUARE	Can be shown how to use for square cut — will need follow-up to make certain it is being used properly.	Usually uses square as a normal process in laying out lines for cutting.	Has little difficulty squaring a line.
USE OF RULER	Should read and measure full inches.	Should read half and quarter inches.	Should read eighth inches. Should read sixteenth inches.
USE OF BLOCK PLANE	Most children can use, if adult will adjust blade.	Very few can plane chamfer and bevel. Some can adjust depth.	Most children can adjust blade and operate. Chamfers possible for most.

Figure 4-4. Suggestions for the use of hand tools by young children.

GRADE	K-1	2-4	5-6
USE OF BRACE AND BIT	Have trouble drilling perpendicular and true size holes. Learn to insert auger bit alone.	Use countersink bit. Should be able to choose proper auger bit for size hole they wish to bore.	Use screwdriver bit. Use expansion bit.
USE OF HANDDRILL	More advanced can learn to put drill bit bit into chuck. Usually can't hold drill without wabbling. Occasionally sticks because of strength in wrists.	All cut put drill bit into chuck.	All should be able to use adequately.
USE OF SCREWDRIVER	Not strong enough to turn many screws. Eye-muscular control not well developed — have difficulty keeping pressure on driver as they twist.	Many use screwdriver for opening cans. Usually can be taught skills necessary for fastening with screws.	Most can select proper size and use screwdriver successfully.
USE OF FILE	Can file. Are able to clean file with file card. Muscular control usually inadequate for regular filing or curves.	Learn to file plywood without splitting.	Get concept of file as a cutting tool.
USE OF HAND OR PANEL SAW	Usually cut up instead of down when wood held in vise. Usually cut correctly on box or bench. Usually can cut better using both hands on saw. Great difficulty learning to start on line.	Exceptional children will cut on line. Have sufficient strength, usually can cut with one hand. Still pinch & force saw. About this age have sufficient strength and control to start on line without a trick (filing notch).	Get concept that saw is designed to cut at a particular angle.

BRAIN RESEARCH

A line of inquiry into the functioning of the right and left hemispheres of the brain began in the early 50's with animal studies. Later, individuals who suffered from epileptic seizures were studied after they had undergone surgery to sever the corpus calloesum which connects the two hemispheres. Other studies focused attention on subjects who had experienced damage to one of the two hemispheres of the brain. From these studies it became evident that the left hemisphere tends to be superior at "handling best those tasks in which the stimuli are familiar and verbal in nature, or easily described or labeled verbally, while the right hemisphere excels on tasks involving meaningless shapes or spatial relationships which are too complex or similar to describe or distinguish in words" (Nebes, 1977, p. 102).

> These studies led Bogan (1977) to comment that: Since education is effective only insofar as it affects the working of the brain, we can see that an elementary school program narrowly restricted to reading, writing, and arithmetic will educate mainly one hemisphere, leaving half of an individual's high-level potential unschooled. (p. 143)

Commenting on the same phenomena, Gazzaniga (1977) stated that:

> If the teacher were to be made aware that the child is specialized in visual-spatial skills and the same conceptual problem is introduced, both the discouragement and the subsequent hostility might be avoided if the child is allowed to use his special talents. Conversely, the child with high verbal skills may quite frequently be unable to visualize the spatial aspect of an assigned task; in this case also, far better results could be obtained if he is not forced into academic areas for which he is not naturally equipped. (pp. 94-95)

This research suggests that typical schooling concentrates on left hemisphere dominated learning tasks, which are symbolic, analytical, associative, and propositional, and generally ignores learning tasks at which the right hemisphere is superior, such as perceiving spatial relations and complex wholes.

These findings seem to parallel the work of linguists such as Mandler (1978) who theorizes that there are two types of memory structures or organization: semantic and episodic. Semantic memory stores abstract and factual information (left hemisphere) while the episodic memory structure stores events which are chronological (temporal) or spatial (Scarborough & Blankenbaker, 1983).

Studies of brain growth have revealed that four spurts of growth tend to occur during which brain weight increases from five to ten percent during each spurt. The growth spurts occur during the periods from two to four, six to eight, ten to twelve, and fourteen to sixteen. It has been theorized that these periods of rapid brain growth are most appropriate for providing intensive intellectual inputs. During the plateau periods between these brain growth spurts it is believed that large amounts of information and a wide variety of direct experiences with nature, science, people, and work are needed. These direct experiences would be provided without the pressure to make elaborate inferences and would serve as a basic for the extensive intellectual consideration during the following brain growth spurt (Epstein, 1978).

The research which focuses directly on brain development and functioning is in its infancy but the early findings have excited professionals from a variety of fields and it appears that much will be learned which will be significant to industrial arts educators.

SUMMARY

Industrial arts educators have tended to ignore the research in perceptual-motor development. Little attention is directed to anthropometric data, models of perceptual-motor development, or the basic research which has been undertaken in related fields. All too often industrial arts teachers learn through trial and error how to select experiences which are appropriate to the development level of their students. We are unable to document through valid research findings that the field makes a significant impact on the perceptual-motor development of the students enrolled in our programs.

It is imperative that we carefully study the anthropometric data to determine how they relate to establishing realistic expectations for our students. Models of perceptual-motor development need to be adopted or adapted to guide the organization of instruction and the planning of research. These models would serve as a basis for theory building and would provide a rational means for making decisions regarding the experiences we provide our students. We must become keenly aware of the research which has been and will be conducted in related fields such as physical education, psychology, industrial engineering, bio-engineering, dance, computer simulation, and military training. By focusing considerable professional energy on the problems of perceptual-motor development, it can be expected that the achievement of our students will be increased and the contribution of industrial arts to the education of children and youths will be enhanced.

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Chapter 5

Assessing Perceptual and Psychomotor Aptitudes and Abilities

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Contemporary American society expects its educational offerings to assist youth in developing and maturing as informed, capable, self-directed, productive, and contributing members of society. Industrial arts education, as part of the general educational system, is designed to help learners develop their awareness, their self-concepts, their special abilities and interests in order to promote their eventual optimum participation in an industrial-technological society. Moreover, industrial arts education has been recognized as the pre-eminent curriculum that helps male and female adolescents develop a technological/industrial literacy. That curriculum has also ably provided youth with an exposure to and understanding of the contributions of industry to the American free enterprise system. As a medium of industrially related exploration and self-assessment, industrial arts programs are of inestimable value.

Carrel (1972), in reporting on and synthesizing the work of others in relation to industrial arts, cited that both general academic and industrial arts education have goals related to the fostering of independent learning by every student. He noted that in the industrial arts curriculum, learning embraces the development of problem-solving and creative abilities, talents, interests, aptitudes, and skills.

The American culture is industrial, technological, and commercial in nature. Contemporary readings attest to its present day dynamic as a high-technology generator, as evidenced by the development of such technical horizons as micro-electronics, robotics, solar energy, computer science, and fiberoptics among others. As the society is democratic as well, it espouses informed individual choice related to education and career. Such concepts have important meaning for the education system (Herr and Long, 1984). In conjunction with these historical and broad themes of general academic and industrial arts education, one finds a surging thrust of concern for exploratory and developmental activities in relation to decision-making and career staging.

In 1972, the industrial arts were more fully incorporated into the career preparation scheme by the provisions of PL92-318 — the Education Amendments of 1972 (passed June 23, 1972). Career preparation here is interpreted as career relevant education, not as vocational preparation for a specific occupation.

The 1972 act mandated that industrial arts programs also provide occupational information related to a broad range of occupations, provide experiences in shops and labs in business and industry to acquaint students with jobs and prepare students for enrollment in advanced and highly skilled vocational and technical educational programs. Such expectations imply not only the instructional but the developmental, the informational, exploratory, motivational, and assessment dimensions and outcomes of industrial arts experiences for youth. Such programs go well beyond merely exposing youth to industrial enterprise. They are formally concerned with one's personal assessments concerning self-identity and aspiration, decision-making, and career planning and development.

Career development tasks and sequences have been classified in a variety of ways (Super, Starishevsky, Matlin and Jordaan — 1963; Tennyson, Hansen, Klaurens and Antholz — 1975). Herr and Long (1979), in describing instructional strategies for career development, cited the following sequence of stages: awareness, exploration, motivation, decision-making, preparation, entry, maintenance, progression, and decline.

Using that staging sequence, one can readily sense the value of industrial arts and skill evaluation programs as they interface with, at the minimum, the first five stages (awareness of self, awareness of the world of work, exploration, motivation, decision-making) and, to some degree, in pre-vocational and vocational programs, (the sixth stage preparation).

Need for Skill Observation and Assessment

Responsible self-fulfillment through wise career decision-making would suggest, at a minimum, one's disciplined personal assessment related to ability, aptitudes, personality, interests, and values.

When considering current expectations of both general academic and industrial arts education along with this technological society's interest in promoting career-relevant education for its citizens, one readily senses the need for observation and measurement of other non-traditional work and skill related traits. Such assessment areas for consideration include innate psychomotor skills, potential and acquired skills, all measured in relation to one's interest in pursuits associated with use of those skills. Needless to state, such assessments demand that associated measurements be realistic, accurate, and reliable, therefore predictive.

Schools can be characterized as doing an acceptable job of measuring cognitive skills and as doing a fair job in the affective realm. However, measurement of movement (psychomotor) behaviors and competencies is relatively unavailable to most students except as measured by a few manipulative and form-board like instruments. The assessment of motor skills and capabilities beyond those normally measured by paper and pencil and simple tests of dexterity would be of great career development assistance to both youth and adult learners. Today, such measures are available and the information they provide enables teachers and counselors to evaluate the learner's manipulative and interpretive competence as well as interest in the tasks measured. The learner is helped to understand the relationship between skills and interests and occupational clusters and careers. Such information helps learners challenge or corroborate curricular and occupational choices.

THE PSYCHOMOTOR DOMAIN

Psychomotor Skills — Skilled Movement

The psychomotor domain is concerned with movement behaviors. Krathwahl, Bloom, and Masia (1964) described the psychomotor area as being concerned with manipulative and motor skills and acts requiring neuro-muscular coordination.

Harrow (1972) noted that when the term is segmented into "psycho" and "motor" components, it connotes mind-movement or voluntary motion and that the domain includes all observable voluntary human motion. She felt that the domain includes those actions performed by a learner and designated by the educator as being essential curricular objectives.

The psychomotor taxonomy developed by Harrow (1972) complemented the work of Krathwahl, Bloom, and Masia (1964) and of Bloom (1956) related to the cognitive and affective domains. Harrow's (1972) taxonomic model classified movement behaviors into six major levels. Each level is further divided into categories and division schemes.

Another classification scheme for behavioral objectives in the psychomotor domain was developed by Simpson (1966). That taxonomy is based on one's perception, disposition to act, and performance of motor activities.

Shemick (1977) capably reviewed several psychomotor classification models and offered his own taxonomy for psychomotor skill tasks. His is a three level taxonomy which classifies skills as being either cognitive-motor, verbal-motor, or sensory-dependent. Shemick's model is predicated on an eclectic hierarchy which begins with simple gross muscle movement and ends with complex fine muscle movements. Fleishman (1970) developed a model which relates to the ability requirements of tasks under consideration. His taxonomy of psychomotor skills includes (1) perceptual motor abilities, (2) abilities of strength and stamina, (3) fine manipulative abilities, (4) gross physical proficiences, (5) perceptual abilities, and (6) auditory perceptual abilities.

While various taxonomic models address all types of psychomotor movements, certain models have more applicability to skill diagnosis and assessment in blue and white-collar trades and technologies. For example, most trade, technical, and fine arts occupations would relate to basic fundamental movements, perceptual abilities, strength, and skilled movements. It seems that those motor behaviors typical of the types needed in trade and technical occupations would be classified in the various taxonomies in different fashions. Researchers and practitioners, therefore, must identify the most appropriate and logical classification of movement behaviors that is consistent with theories and principles of movement as well as the one which discriminates the tasks under study. The user must assure that the choice of taxonomy reflects a value for research or for facilitating the organization of curricular content and the structuring of evaluations of outcomes of learning sequences provided.

Harrow (1972) noted that when one performs purposeful movements, one is coordinating the cognitive, affective, and psychomotor domains. She also noted that one's movement is modified by past learnings, environmental surroundings, and by the situation being addressed. These observations impute considerable meaning to those educators interested in meaningful and dexterous skill development in learners.

Cratty (1964), himself a developer of a theory of perceptual motor behavior, noted that one's perception of movement tasks affects the performance of the mechanics of the task. Harrow (1972) in noting that some tasks require cognitive, affective, and psychomotor investments made the point that recognition of and attention to such domain involvement and overlap can enhance efforts to develop and improve motor skills.

Many curricular areas (physical education, industrial arts, vocational education, fine arts, special education) are highly associated with movement proficiency. Educators and researchers associated with these disciplines continue to investigate the relationships between motor development and proficiency and academic and occupational performance. Such investments hold much promise for those interested in diagnostic skill evaluation.

Aptitudes, Interests and Skills

No matter how exhaustive and thorough the evaluation of an individual's psychomotor performances may be, it would appear to be insufficient in promoting optimum career development or even in making embryonic strides towards that end without supplemental enlightenment regarding one's self-awareness and interests. An organized sequence is needed to enable the individual to proceed through a variety of experiences to learn more about self and how one can successfully relate to and position oneself in the world of work. Such experiences should provide an appropriate world-of-work atmosphere and no unnecessary barriers to successful participation, i.e., reading and writing skill levels. Such sequences would provide the individual with realistic opportunities and assistance in recognizing and exploring aptitudes, interests, and skills in a meaningful, understandable, and practical fashion. It is a truism that aptitude plus interest equals achievement. Achievement in the world of work comes through the identification, development, and appropriate use of one's skills.

SKILL ASSESSMENT TECHNIQUES

Trait assessment of all types relates to the inventory function of guidance services. That function itself is based on the premise that self-awareness stemming from measurement activities (in this case skill assessment) leads to more informed development and application of native and acquired skills. That is, a good assessment of personal capabilities, coupled with the use of accurate educational and occupational information, leads to better counseling, decision-making, educational choice, and placement, all of which augment eventual adjustment to the world of work. Personal skill evaluation then is an important career development experience. It helps an individual make career decisions with a higher degree of fidelity.

Until recently, career guidance has relied mainly on the traditional paper/pencil and form board approaches to the measurement of abilities, interest, and skills. That situation, however, is changing.

Formal/Informal Skill Assessment

Skill assessment can occur in any situation, location, and at any stage of life. Assessment can occur in school activities and in everyday living experiences. Assessments can be made by others and shared with clients or they can be self-assessments. Moreover, skill assessments can be formal or informal; and as Humphreys, Traxler and North (1967) noted, scientific or casual. Formal to some might mean standardized; to others, in school. Informal to some might mean self-assessment, on-job assessment, or elective testing.

A paradigm which will be useful when considering these relationships is offered in Figure 5-1.

Cell 1 of the skill assessment model can be characterized as including all school based, standardized psychometrics. The school mediates the program and uses the results obtained with students, counselors, teachers, and parents for both curricular and guidance purposes.

Cell 2 would include all community-based standardized measurements such as GATB testing by Job Service (formerly the Bureau of Employment Security), industrial and commercial employment tests, apprentice board examinations, and sheltered workshop assessments among others. Community agencies other than schools mediate those programs. Results are not necessarily shared with schools even when such results describe students still enrolled in school.

Cell 3 represents in-school measures or estimates obtained by nonstandardized observations. They can be collected by teachers, activity supervisors, athletic coaches, and instructional aides, among others. They *might* be shared with colleagues and parents. They *might* have curricular and guidance importance.

	School-Based	Community-Based
Formal/ Scientific	1	2
Informal/ Casual	3	4

Figure 5-1. Skill Assessment Model

Cell 4 includes all informal observations stemming from out-of-school activities. They might be shared with clients and others interested in the client's development. They would include assessments related to scouting or 4H activities, work experience programs, hobby, and volunteering activities.

While skill assessments from all sources described in the model can relate to educational and occupational decision-making, it appears that Cell 1 and 2 assessments have the most utility and likelihood for being used for educational and career purposes. This utility seems to be highly associated with both the standardized formality of the assessment structures, the instruments used, and the organizational locus of the assessment. Cratty (1964) noted that there are two types of perceptions — those about self and those about concepts and objects. Cells 1 and 2 seem to relate to assessments about the self in relation to skills concerning concepts and objects and use of that information in related curricula.

Cells 3 and 4 possibly provide more assessments related to self than to objects and concepts. Even though activities in those cells provide many opportunities and much information for a wise advocate to use to structure self/concept/object understandings, it would seem common practice has it that observations of the individual are emphasized at the expense of concept/object/skill perceptions.

Assessments of self or of things by self or by others serve best when they are used to help individuals be reflectively cognitive about them. Only then can they be meaningful and structural for the individual.

Standardized Testing

The formality of standardized testing is brought about by the measurement techniques and controls employed and by the criterion-oriented normative data associated with the various types of instruments.

Standardized testing is mainly cognitively based. Traditionally, it employs paper-and-pencil oriented instruments. It is commonly associated with measurements of intelligence, achievement, academic aptitude, interests, reading, personality, and adjustment. Much of it exposes the examinee to abstract stimuli only. For some youths and adults, such an indictment cites a serious limitation regarding traditonal standardized testing activities. While certain examinees can handle abstraction well, others do better with tangible and concrete stimuli. Moreover, Barclay (1968) noted that educators far too often accept a test score as an ultimate criterion.

Nunnally (1959) noted that the first psychological tests were mainly measures of sensory abilities, sensory thresholds, reaction time, and sensory acuity. He also noted that there was an early disenchantment with those more-or-less psychomotor-oriented instruments because they failed to predict school grades, teacher ratings of intelligence, and other indices of intellectual achievement.

Bauernfeind (1968) cited a series of studies in which teachers' preferences for various types of standardized test data were ranked. He noted that for surveyed teachers an "attractive testing program" would rank basic skills information first, a not too surprising finding. It was disquieting, however, to note that teachers gave low ratings to measures of vocational aptitude, spatial ability, and dexterity among others. Moreover, teachers felt that such information would not help them in their work with children, and that they could readily identify such talents without the use of tests. Bauernfeind noted that while many teachers held these feelings, one could question the accuracy of the assertions.

Considering today's interest in career education, skill training, adult education, and special-needs learners, one readily recognizes the need for assessment of other human traits and attributes than those normally addressed in the cognitive domain. Cognitive measurements alone seem inadequate to help potential job seekers make career choices in this complex technological society.

Measurement Using Work Samples

Assessment efforts which utilize work samples augment standardized cognitive skill measurement. In 1970, Pruitt classified work samples as being: (1) simulated, a mock-up or close simulation; (2) actual, a small sample from an actual job; or (3) isolated trait, which assesses a specific trait, i.e., sorting, finger dexterity.

Work-sample skills assessment has the following advantages: It uses actual job tasks which provide a closer congruity and match between evaluation and task performance. Work-sample assessment can attend to skills of all sensory and motor areas — spatial, temporal, visual, auditory, tactile, and manipulative. Furthermore, it promotes the observation and assessment of movement behaviors.

Work-sample assessment can be done in skill evaluation centers or on the job. In both cases skills can be evaluated in context; that is, one's aptitude for, attitudes toward, interest in, and approaches to tasks can be assessed.

Moreover, work-sample assessment requires only minimal reading and verbal skills. Work samples generate less measurement anxiety and they induce motivation in the examinee. The examinee mediates work-sample assessment activities in terms of time invested, quality of performance, and the types or work samples experienced. On the other hand, the examiner has the opportunity to observe client performance casually and informally or in a more scientific, standardized, normative fashion.

Finally, work samples involve both minds-on and hands-on assessment. With minimum supervision by the examiner, work-sample assessment can help create a new self-vision for the examinee.

NEW ASSESSMENT STRATEGIES

Work-Sample Assessment

Work samples have most likely been utilized for generations in a wide variety of unpolished, practical forms in numerous education, job-training, and world-of-work settings. They did not, however, become widely known or marketed products of more sophisticated nature until the mid 1970's when professionals began to find them advertised and exhibited at professional gatherings and conventions. One is still hard pressed to find much formalized, work sample research literature without resorting to and investigating the product and sales literature of many companies.

Work samples appear to have developed from a need to determine the most appropriate placement of individuals in training for world-of-work positions. In discussing Job Corps programs, a recent publication noted that following conventional methods of job counseling, about 25 percent of trainees request skill changes. After hands-on work sampling with an evaluation system, "subsequent skill changes have been requested by less than five percent of the participants at the San Jose Corps Center." (Singer News, December, 1982). The article also noted that a Government Accounting Office Report on Job Corps Recruitment and Placement attributed those positive results to experience with hands-on work samples.

Work-sample systems are considered to be hands-on experience or project activities assessment related to training or job-getting situations. In most cases, work-sample assessment eliminates paper-pencil assessment and time consuming trial-and-error placement efforts. It replaces the former with tool and material exercises requiring demonstration and/or verbal instructions for completion. It appears to be widely accepted that the reason for the use of work samples is to assess job skill potentials and work-related behaviors through performance on actual or simulated job tasks. For a much more in-depth look at work samples, the reader might refer to such materials as Project Assist of the Pennsylvania Advisory Council on Vocational Education (1981) and vocational evaluation system product literature.

Botterbusch and Sax (1977), in presenting some considerations for the establishment and implementation of an evaluation unit and selection of a commercial vocational evaluation system, cite the following four aspects they feel should be analyzed: (1) the relationship between the community and the vocational evaluation unit, (2) the client population, (3) the purpose of evaluation, and (4) "why even purchase a commercial evaluation system at all?"

The fourth point deserves special attention. If actual local job samples can be developed for evaluative or training purposes, that option could certainly be the least expensive and even, perhaps, the most effective course of action. If not, consideration would turn to commercially produced work samples and should involve extensive research.

Each marketed work-sample system has its unique qualities and system of evaluation as well as rating designations. A potential user/purchaser of work samples needs to look carefully at available products in terms of numerous criteria tailored to the designated use setting. Examples of elements to be considered include: (1) clientele to be served, (2) objectives and outcomes desired, (3) purchase cost, (4) operational and maintenance costs, (5) agencies and/or referral systems to be utilized, (6) time requirements and constraints of the evaluation system, (7) required and/or needed personnel training, (8) personnel required for operation and level of educational attainment of same, and (9) the space available — physical setting.

Assessment instruments change and new ones become available. For these and other obvious reasons, it behooves the potential user of work-sample systems to seek the advice and opinions of inservice personnel and to carefully scrutinize the literature that is available. Some prominent literature related to work samples includes three comparative studies available from the Materials Development Center of Stout Vocational Rehabilitation Institute, University of Wisconsin (Botterbusch 1976, 1977, 1982) and *A Counselor's Guide to Vocational Guidance Instruments* published by the National Vocational Guidance Association (1982).

It is a seemingly salient practice of inservice personnel dealing with work-sample assessment and evaluation to seek out colleagues for advice and assistance. Other sources of information are somewhat lacking.

Worker-Trait Assessment

Worker-trait assessment involves a diversity of terminology used in the various work-sample systems. Each system, with its own terminology and area(s) of emphasis, attempts to evaluate an individual's relationship to the world of work through performance in a simulated work setting. That evaluation is done in terms of specific traits, factors, and characteristics. Evaluations include reference to such classifications as:

1. Personal Elements: punctuality, attendance, personal hygiene, dress, physical description.
2. Performance Qualities: interaction with co-workers and supervisors; reactions to such things as praise, criticism, and job change; discrimination of size, color, and space; measuring and numerical abilities; dexterities; coordinations of eye/hand/foot;

tolerance levels for frustration, repetitive work, sitting, bending, lifting, and standing; working under pressure; pace of work; sensitivity to conditions; attitudes; quality appreciation; neatness in work.

3. Actual performance on work-sample projects in terms of time spent and quality of work on pre-determined evaluation/grading standards.
4. Interest of the client in areas representing the world of work and job training.

The most desired evaluations would appear to be of aptitude (including skills) and interest.

Buyers, developers, and users of work-sample systems must look critically at the potential evaluator time, subjectivity and objectivity, and paper data (i.e. scoring, scaling) that could be involved in the production of the final profile of a client being processed in work-sample assessment and exploration.

Major Skills Assessment Systems

Here presented to the reader is a description, in very abbreviated format, of the work-sample/skills assessment systems that are available. The more curious reader might refer to the comparative studies cited for more detailed information. (*Systems are presented in alphabetical order.*)

Comprehensive Occupational Assessment and Training System (COATS). This is a ten work sample system based on a job family system:

1. Drafting
2. Clerical-Office
3. Metal Construction
4. Sales
5. Wood Construction
6. Food Preparation
7. Medical Services
8. Travel Services
9. Barbering-Cosmetology
10. Small Engine

The system contains four components: (1) Job Matching System, (2) Employability Attitudes System, (3) Work-Samples System, and (4) Living Skills System. Work samples are evaluated using time and quality norms. The final report form is computer-generated and is done by the product company.

The Career Evaluation System (Career Hester — Series 200). This newest version of the original "Hester" system is not a true work sample system but is a battery of psychological and psychophysical tests. The results are geared to the fourth edition of the *Dictionary of Occupational Titles.*

The system contains 26 separate performance and paper/pencil tests that provide a total of 39 scores. Directions are oral. Demonstrations augment the work-sample segments. Scoring emphasis is on completion time, how much is completed during a given time, or number of correct responses. The final report is computer generated at the corporate home base and contains: demographic and identification data supplied by the evaluator, scores for each test, client level of functioning in data-people-things hierarchies, feasible worker-trait groups for client consideration and a selected list of job titles for the client to consider.

Hester Evaluation System. This system involves 28 performance and paper/pencil tests grouped into seven categories:

1. Unilateral Motor Ability
2. Bilateral Motor Ability
3. Perceptual (speed, accuracy, and spatial)
4. Intelligence
5. Achievement
6. Physical Strength
7. Perceptual (motor senses)

The client profile is computer generated at the home base and contains: demographics and identification supplied by the evaluator, scores for each test, client level of functioning in data-people-things hierarchies, feasible worker-trait groups for client consideration, and a selected list of job titles for client use.

JEVS System (Jewish Employment and Vocational Service). JEVS is a 28 work sample system arranged in the following Worker Trait Groups relating to the *Dictionary of Occupational Titles (DOT)*:

1. Handling
2. Sorting, Inspecting, Measuring and Related Work
3. Tending
4. Manipulating
5. Routine Checking and Recording
6. Classifying, Filing, and Related Work
7. Inspecting and Stock Checking
8. Craftsmanship and Related Work
9. Costuming, Tailoring, and Dressmaking
10. Drafting and Related Work

Performance is rated on time, and provision is made for observation of specific work factors inherent to each work sample.

McCarron-Dial Work Evaluation System. This system has 17 tests, tasks, and scales grouped into the following three neuropsychological factors:

1. Verbal-Cognitive
2. Sensory
3. Motor Abilities — Fine and Gross Motor Skills Assessment

Evaluations combine time and quality norms in a single raw score for each major area with conversion to percentile results.

Micro-TOWER. This is a 13 work-sample system divided into five groups:

1. Motor: Electronic connector assembly, bottle capping and packing, and lamp assembly
2. Spatial: blueprint reading and graphic illustration
3. Clerical Perception: filing, mail sorting, zip coding, and record checking
4. Numerical: Making change and payroll computations
5. Verbal: Want ads comprehension and message taking

Evaluation includes both time and quality ratings with a behavioral observation form for five work behaviors.

Occupational Assessment/Evaluation System (OA/ES). This system consists of paper/pencil tests, inventories, checklists, apparatus tests, and optional work samples. The following 11 aptitudes are measured:

1. Intelligence
2. Verbal
3. Numerical
4. Spatial
5. Form Perception
6. Clerical Perception
7. Motor Coordination
8. Finger Dexterity
9. Manual Dexterity
10. Eye-Hand-Foot Coordination
11. Color Discrimination

The independent work samples include:

1. Systems Planning
2. File Management
3. Order Request Processing
4. Product Identification
5. Grinding Operations
6. Drill Press Operations
7. Electro-Mechanical
8. Welding
9. Itinerary Planning

In evaluating work sample performances, the client is not timed, but a cut-off time is utilized on some of the samples. Work sample instructions are given orally along with demonstrations. OA/ES scoring emphasizes the number of correct responses. OA/ES includes a "Behavioral Summary Sheet" listing nine work behaviors, i.e., frustration, maturity. Also in the reporting system is an "Evaluee Reporting Form" incorporating five questions about how the client liked the work sample. The results of paper/pencil tests, inventories, checklists, and apparatus tests appear summarized in a computer-generated final report form.

Pre-Vocational Readiness Battery (Valpar 17). This system contains five areas, each having several separate subtests:

1. Development Assessment: contains four parts which are "simple, functional, non-medical measures of physical and mental abilities" — (a) patterning/color discrimination manipulation, (b) manual coordination, (c) work range/dynamic strength/walking and (d) matching vocational knowledge/measurement.
2. Workshop Evaluation.
3. Vocational Interest Screening: incorporates six area scores — social service, sales, machine operation, office work/clerical, physical sciences, and outdoor.
4. Social/Interpersonal Skills: Four major areas are covered — (a) personal skills, (b) socialization, (c) aggravating behaviors, and (d) work related skills.
5. Independent Living Skills: An Assessment of — (a) transportation, (b) money handling, (c) grooming, and (d) living environments.

Instructions vary depending upon the client's needs. Scoring emphasis is on the number of correct responses. None of the selections identify specific work performance factors. Work behaviors are included in a section titled "Interpersonal-Social Skills."

The System for Assessment and Group Evaluation (SAGE). SAGE is a four-part assessment system. It includes:

1. The Vocational Interest Inventory.
2. The Cognitive and Conceptual Abilities Test.
3. The Vocational Aptitude Battery (VAB) — Eleven hands-on assessment instruments that measure the following aptitudes:
    - General
    - Verbal
    - Numerical
    - Spatial
    - Form Perception
    - Color Discrimination
    - Clerical Perception
    - Motor Coordination
    - Finger Dexterity
    - Manual Dexterity
    - Eye-Hand-Foot Coordination
4. The Assessment of Work Attitudes.

Times and correctly completed tasks are recorded. The results report the level of functioning for the client in each specific aptitude.

Singer Vocational Evaluation System. The Singer system includes 25 work-sample units representing areas or fields of job-getting or training. It includes an interest test relating to each of the work-sample units plus a few additional areas. Work-sample units are available in the areas of:

1. Basic Tools
2. Electronics Assembly
3. Drafting
4. Plumbing/Pipefitting
5. Woodworking
6. Refrigeration/Heating/Air Conditioning
7. Welding and Brazing
8. Sales Clerk
9. Needle Trades
10. Masonry
11. Sheet Metal
12. Cooking/Baking
13. Engine Service
14. Medical Services
15. Cosmetology
16. Data Calculating/Recording
17. Soil Testing
18. Production Machine Operation
19. Household/Industrial Wiring
20. Filing, Shipping, and Receiving
21. Package and Materials Handling
22. Office Services
23. Information Processing
24. Bench Assembly
25. Basic Laboratory Analysis

Performance is rated on time and quality standards. A work factor report of observable worker characteristics is included. Work sample projects are completed by the client with detailed instructions and demonstrations given via a filmstrip projector with a coordinated cassette tape.

Talent Assessment Programs (TAP). TAP is an 11 work sample system organized into the following areas:

1. Structural and Mechanical Visualization
2. Discrimination by Size and Shape
3. Discrimination by Color
4. Tactile Discrimination
5. Fine Discrimination without Tools
6. Gross Dexterity without Tools
7. Fine Dexterity with Tools
8. Gross Dexterity with Tools

*9. Circuital Visualization

10. Retention of Structural and Mechanical Detail

*11. Structural and Mechanical Visualization in Greater Depth

*The most recent edition of TAP replaces #9 with Flowpath Visualization and eliminates #11.

Instructions accompany demonstrations. Evaluations include time and quality measures. TAP is recommended to be used with other assessment devices if more than the perceptual and dexterity results mentioned above are desired.

The TOWER System. TOWER is a 93 work sample system arranged in the following 14 job training areas:

1. Clerical
2. Drafting
3. Drawing
4. Electronics Assembly
5. Jewelry Manufacturing
6. Leathergoods
7. Machine Shop
8. Lettering
9. Mail Clerk
10. Optical Mechanics
11. Pantograph Engraving
12. Sewing Machine Operating
13. Welding
14. Workshop Assembly

The work samples are administered using mainly written instructions supplemented with verbal explanations and demonstrations as needed. Evaluations use time and quality standards and are reported with global factors about the client in the final rating.

VALPAR Component Work Sample Series. VALPAR comprises 12 work samples to be used independently:

1. Small Tools (mechanical)
2. Size Discrimination
3. Numerical Sorting
4. Upper Extremity Range of Motion
5. Clerical Comprehension and Aptitude
6. Independent Problem Solving
7. Multi-Level Sorting
8. Simulated Assembly
9. Whole Body Range of Motion
10. Tri-Level Measurement
11. Eye-Hand-Foot Coordination
12. Soldering

Instructions are given orally and through demonstration. Evaluation utilizes both quality and quantity measures. Each sample is evaluated on the basis of the same worker characteristics.

Vocational Information and Evaluation Work Samples (VIEWS). VIEWS is an adaptation of the JEVS System to be used for mild, moderate, and severely retarded persons requiring a one-on-one client/evaluator administration. This system contains only 16 of the JEVS work samples grouped into the following four areas.

1. Elemental Area of Work: Handling Worker Trait Group (WTG)
2. Clerical Area of Work: Routine Checking and Recording WTG
3. Machine Area of Work: Tending WTG
4. Crafts Area of Work: Manipulating WTG

Refer to JEVS System for evaluation process and other details.

Vocational Interest, Temperament, and Aptitude System (VITAS). This system is comprised of 21 work samples used to assess work potential in terms of interest, temperament, and aptitudes. VITAS relates to the following Worker Trait Group Arrangements in the *Dictionary of Occupational Titles (DOT).*

1. Handling
2. Tending
3. Manipulating
4. Switchboard Service
5. Routine Checking and Recording
6. Sorting, Inspecting, Measuring and Related
7. Computing and Related Recording
8. Inspecting and Stock Checking
9. Cashiering
10. Classifying, Filing and Related
11. Information Gathering, Dispensing, Verifying
12. Paying and Receiving
13. Technical Work, Science and Related
14. Craftmanship and Related
15. Drafting and Related

Vocational Skills Assessment and Development Program (Brodhead-Garrett). The Brodhead-Garrett system is a three-phase system that uses work samples in the first phase. The work samples relate to the following three types of activities: (1) Sorting, (2) Assembly, and (3) Salvage. The second and third phases are generalized plans, goals, and curriculum for in-depth occupational exploration and skill training.

No work behaviors are related specifically to the work samples. Time and quality of performance are equally emphasized in the scoring. The final report is generated at the evaluation site and contains a sheet on which to plot the performance tasks plus the following types of information: demographics, initial information, vocational assessment, recommendations, academic history, and employment history.

Wide Range Employment Sample Test (WREST). WREST is comprised of ten work samples to be used independently:

1. Single, Double Folding, Pasting and Stuffing
2. Stapling
3. Bottle Packaging
4. Rice Measuring
5. Screw Assembly
6. Tag Stringing
7. Scratch Pasting
8. Collating
9. Color and Shade Matching
10. Pattern Making

Work samples are administered using oral instructions and demonstrations. Final evaluation utilizes both time and quality standards.

Work Skill Development Package (WSD). WSD is a 20 work-sample system arranged into three groups:

1. Discrimination Tasks: three-item sort, subtle color, rubber parts sort.
2. Assembly Tasks: tube assembly/disassembly, coupling assembly/disassembly.
3. Packaging Tasks: color match collating/collating disassembly, small parts packaging/disassembly.

Instructions are given verbally and through demonstration. Time and accuracy are equally considered in scoring. It appears that no observation regarding work performance or work behavior is included. The system was originally designed to be a training device but is also suggested for use as an evaluation system. No final report form is available.

At the last, there are many work-sample systems that have not been formally marketed but are designed for specific situational use. There was no intent here to promote any particular work sample system. An attempt was made to present the reader with enough information about various systems that have been marketed to develop an understanding of their diversities. The interested reader can refer to the product references list for the company address for each of the work sample systems discussed.

IMPLICATIONS FOR TEACHERS

1. Teachers should recognize that both formal and informal classroom assessment activities have potential for moving learners to higher stages of career poise in terms of their personal skills, identities, self-awareness, self-perceptions, skilled performances, and improved decision-making.

2. Skill evaluation activities enable teachers and counselors not only to observe but to record, evaluate, and describe the skilled behaviors of students.
3. The technical expertise represented in the Industrial Arts teacher puts him/her in a position to be the local pioneer in the establishment of practical forms of work sample assessment. For example, a classroom using a variety of types of fasteners might incorporate a sorting work sample to evaluate an individual's ability to discriminate among various types, sizes, and forms and to sort like items. The benefits of such endeavors at the local level would be endless and the expense would be minimal.
4. Teachers should be attentive and responsive to the need for provision of classroom/laboratory climates that foster the exploration of personal capabilities through measurement of manipulative behaviors.
5. Teachers, while observing many behaviors, should recognize that the assessment of capability is underlined with the need for objective evidence concerning interests, abilities, aptitudes, and skills.
6. A teacher's utilization of work sample assessments would help students develop informed sensitivity and awareness of their individual capabilities, interests, and potentials.

IMPLICATIONS FOR TEACHER EDUCATION

1. Teacher education programs should help each Industrial Arts teacher to consider him/herself to be a vital part of every student's guidance and career decision-making process.
2. Teacher education programs should help prospective teachers recognize that while Industrial Arts programs are directed toward exposing youth to various technologies and their relationship to industry, they can also provide personally relevant and valuable information related to interests, skills, and potentials.
3. Teacher education programs should expose prospective Industrial Arts teachers to information about skill evaluation systems and their relationship to exploratory experiences for self-evaluation and decision-making.
4. Teacher education programs should provide teachers in programs that require psychomotor competence with a sense of the guidance utility of skill evaluation measures. Special atten-

tion should be given to those skills and talents that are not measured in traditional school testing programs.

5. Teacher education programs should help prospective teachers to consider it their responsibility to assist all students in gaining broad insight into the world of work so that when decisions must be made the individual student will be equipped with not only general occupational information but also with personal information relating to aptitudes, interests, skills, and potentials.

SUMMARY STATEMENT

Career development does not occur without self-direction and the assistance and advocacy of others. That assistance oftentimes relates to assessment of an individual's capability, interest and potential. The assessment of perceptual and psychomotor abilities assists individuals in the achievement of the realities possible for them. As such, it deserves the attention of all educators. This chapter hopes to give direction to educators interested in that task.

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PRODUCT REFERENCES

COATS:
Prep, Inc.
1007 Whitehead Road Extension
Trenton, NJ 08638

Career Evaluation System (Career Hester):
Career Evaluation Systems, Inc.
7788 Milwaukee Avenue
Niles, IL 60648

McCarron-Dial Work Evaluation System:
McCarron-Dial Systems
P.O. Box 45628
Dallas, TX 75245

JEVS:
Vocational Research Institute
Jewish Employment and Vocational Service
1700 Sansom Street, 9th Floor
Philadelphia, PA 19103

Hester Evaluation System:
Career Evaluation Systems, Inc.
7788 Milwaukee Avenue
Niles, IL 60648

TOWER:
International Center for the Disabled
340 E. 24th Street
New York, NY 10010

Micro-TOWER:
Micro-TOWER
ICD Rehabilitation and
Research Center
340 East 24th Street
New York, NY 10010

OA/ES:
Individualized Rehabilitation
Programs
42 West Park Avenue
Long Beach, NY 11561

Pre-Vocational Readiness Battery (Valpar 17):
Valpar International
3801 E. 34th Street, Suite 105
Tucson, AZ 85713

SAGE:
Progressive Evaluations
Systems Corp.
21 Paulding Street
Pleasantville, NY 10570

Singer Vocational Evaluation System:
Singer Career Systems
P.O. Box 23570
Rochester, NY 14692

TAP:
Talent Assessment, Inc.
P.O. Box 5087
Jacksonville, FL 32207

VALPAR:
Valpar International
3801 E. 34th Street, Suite 105
Tucson, AZ 85713

VIEWS:
Vocational Research Institute
Jewish Employment and
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VITAS:
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1700 Sansom Street, 9th Floor
Philadelphia, PA 19103

Vocational Skills Assessment and Development Program (Brodhead-Garrett):
Brodhead-Garrett Company
4560 East 71st Street
Cleveland, OH 44105

WSD:
Attainment Company
P.O. Box 103
Oregon, WI 53575

WREST:
Jastak Associates, Inc.
1526 Gilpin Avenue
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Chapter 6

Measuring Psychomotor Skills and Performance

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Measurement of psychomotor skills and performance in industrial arts education classes is concerned with assessing those physical or motor tasks that students are to have developed as a consequence of their having participated in the instructional program. The skills and performances to be measured can range from simple to complex, depending upon the students' grade level and developmental needs. Many industrial arts program objectives, whether for elementary grade, junior high, senior high, or adult learners, stress the importance of students at least "trying their hands" at learning to perform certain tasks with the tools, materials, and equipment of "industry."

This chapter will focus on the goals and purposes that form the bases for psychomotor skill and performance objectives in industrial arts programs and describe a model for assessing students' attainment of these objectives. Special emphasis will be placed upon examples of the types of instruments that would be useful to industrial arts educators in making the types of assessments presented in the model.

Skill Development in Industrial Arts Programs

All of the widely accepted definitions of industrial arts education characterize it as being the broad study of the tools, materials, equipment, processes, products, and occupations of industry which is pursued for general education purposes in school laboratories and drafting rooms. One key element in these definitions is *pursued for* *general education* purposes. This is the element that draws the distinction between industrial arts and vocational industrial, trade and industrial, and technical education.

It follows then that all psychomotor skill development in industrial arts is for general education purposes. The skills developed are thought to be important to the education of *all* students. For some students industrial arts may have prevocational or even vocational values. However, the primary purpose of industrial arts is not to provide specialized vocational instruction for students.

It was within this context that the first committee on "Standards for Attainment in Industrial Arts Teaching" included the following two objectives among its published twelve goals for industrial arts education.

> — To develop in each pupil a knowledge and understanding of mechanical drawing, interpretation of the conventions in drawings and working diagrams, and the ability to express his ideas by means of drawing.
>
> — To develop in each pupil elementary skills in the use of the more common tools and machines in modifying and handling materials, and an understanding of some of the more common construction problems. (AVA, 1934, p. 12)

Succeeding goal statements published by the profession (AVA, 1946, 1953) also contained references to the importance of skill development as a goal for industrial arts programs. The last of this series of published purpose statements contains five goals unique to industrial arts education and nearly every one of them suggests the need for hands-on activities coupled with some measure of skill development.

> Goal I — Develop an Insight and Understanding of Industry and Its Place in Our Culture.
>
> Goal II — Discover and Develop Talents, Aptitudes, Interests, and Potentialities of Individuals for the Technical Pursuits and Applied Sciences.
>
> Goal III — Develop an Understanding of Industrial Processes and Practical Applications of Scientific Principles.
>
> Goal IV — Develop Basic Skills in the Proper Use of Common Industrial Tools, Machines, and Processes.
>
> Goal V — Develop Problem-Solving and Creative Abilities Involving the Materials, Processes, and Products of Industry. (AVA, 1968, pp. 9-11)

The most recent Standards for Industrial Arts Education Programs Project sponsored by the U.S. Department of Education identified eight major purposes of industrial arts education. The first five testify as to the importance of learning through hands-on experiences with tools, equipment, and materials as well as developing a measure of skill while so doing. To be certain that programs measure "up to standard," it is suggested that program emphases be placed upon:

> — assisting students in developing insight and understanding of our industrial and technological society;
> — improving student ability to make informed and meaningful occupational choices;
> — preparing students for entry into trade and industrial, technical, or other advanced education programs;
> — developing student talents, creative abilities, positive self-concepts, and individual potentials related to industrial-technical areas; and
> — developing student abilities in the safe and proper use of tools, materials, machines, and processes. (AIAA, 1980, pp. 14-15)

Of the fifteen purpose statements for industrial arts education recently published by the American Council on Industrial Arts Teacher Education, no fewer than five stress the importance of students working with tools and materials and learning to perform motor skills. These five indicate that industrial arts programs should assist students to develop:

> — basic skills in use of common hand tools and machines, as well as understanding of various materials and work processes.
> — the capacity for constructive use of leisure time.
> — understanding of a variety of technical and career areas for avocational and prevocational enrichment through exploratory experiences.
> — ability to perform home-related and other technical repairs and constructions for purposes of fiscal economy.
> — craftsmanship and stimulate creative expression and a desire for excellence. (ACIATE, 1982, p. 4)

Clearly, the importance of designing and offering learning experiences that provide industrial arts students with the opportunity to develop a degree of skill and ability in working with industry-oriented equipment, tools, materials, and processes (past, present, and future) is well documented and is recognized by most if not all professionals in the field. Few industrial arts educators would argue the importance of this aspect of their programs. Most would be inclined to argue that skill development in a tools and materials context is the key element in making industrial arts the unique educational program that it is. Without this element, industrial arts classes could come to resemble social studies classes taught in public schools today.

However, many industrial arts educators feel a need to better quantify the degree to which their programs have been successful in teaching the development of psychomotor skills and performance. Considerable *informal* assessment has been carried out. However, more attention needs to be given to *formal* assessment of students' motor skill development in industrial arts classes.

The Importance of Assessing Skill Development

Traditionally, industrial arts educators, along with educators from other curriculum areas have given more time to the formal assessment of cognitive student achievement (i.e., knowledge and understanding) than they have given to formally assessing the degree to which their students have developed certain psychomotor skills and the ability to perform tasks commonly espoused in industrial arts program goals and objectives. The latter they have tended to do on an informal basis as they observed students' progress in the laboratory and/or evaluated the craftsmanship exhibited in students' projects. This should not be the case.

If the development of psychomotor skills and abilities is important in achieving some of the goals, purposes, and objectives for industrial arts programs, then formal assessment of the degree to which students can perform these motor skills or demonstrate these abilities should be an important part of measuring students' achievement and evaluating their progress in the program.

Providing industrial arts students with quantitative, reliable, and valid feedback as to their total performance in the instructional program means that *all* instructional objectives should be the focus of some formal assessment, not just the ones that focus on cognitive behaviors like knowing and understanding. Students need this information for motivational purposes. Parents need this information for parenting purposes. Industrial arts educators need this information for student guidance and evaluation purposes as well as for program evaluation (Wentling, 1980) purposes. No matter how valid, formal assessment of some objectives, goals, and purposes and informal or no assessment of the others will make only limited contributions to the teaching-learning process and the industrial arts program.

SELECTING THE MEASUREMENT APPROACH

The discussion presented thus far might lead one to conclude that cognitive and psychomotor performances are mutually exclusive types of behavior. Not so, for there are very few tools- and materials-oriented psychomotor skills that also do not require associated cognitive behavior; usually either knowledge, understanding, or both. Mr. Dabney Doty, an industrial arts teacher educator at the University of Missouri-Columbia, often reminds his students that "There is more headwork than handwork in shopwork."

Recognition of this fact, unfortunately, has led to a common misconception. It is that assessing achievement of a complex motor task can be accomplished by measuring only part of the behavior, usually the cognitive part. More often than not, a different and more direct approach is required.

Central to whatever approach is used in assessing student achievement of some motor skill or the ability to perform some task are the instructional objectives for the industrial arts course. They should communicate to everyone (students, parents, teacher, program supervisor, etc.) specifically what it is the students will be able to do, under what conditions, and to what degree or standard of performance. For example, an industrial arts skills oriented student performance objective that might follow from the home-related repairs purpose presented earlier in this chapter (ACIATE, 1982) could be:

> *Given a leaky water faucet and the necessary tools and materials, students will be able to diagnose and make the repairs needed for the faucet to perform to manufacturer's specifications.*

DIRECT ASSESSMENT

Direct assessment of this and other student performance objectives of this type is fairly straightforward. It would involve (1) giving the student a leaky faucet (worn washer, eroded seat, and/or worn O-ring) and the appropriate tools and materials, (2) having the student diagnose the problem(s) and make the repair(s), and (3) testing the faucet for leaks after the student finishes making the repair(s). The actual procedures and techniques used to directly assess student attainment of this objective would vary somewhat among industrial arts educators, but the basic plan for direct assessment is always embodied in the objective.

Erickson and Wentling (1968, p. 72) indicate that this is the ideal approach to assessing performance objectives and it should be used whenever possible. However, in the real world, the ideal approach is not always the most practical. Direct assessment of student performance objectives in industrial arts programs is no exception to this observation.

Indirect Assessment

When direct assessment is not practical (or possible), it may be necessary to use indirect assessment. This approach is not so straightforward as direct assessment.

The performance objective still would serve as the focal point for the assessment; however, in indirect assessment of the foregoing objective, the industrial arts educator would ask questions like:

> In order to successfully diagnose the cause(s) of its malfunction(s) and repair this faucet,
> — What must the student know about tools, materials, and repair procedures?
> — What must the student understand about the working relationships between and among the faucet's parts and the water leaking through it?

From answers to these questions, test items would be formed to examine and assess key knowledges and understandings that are requisite to actually being able to diagnose and repair the leaky faucet. These items then would be put in an appropriate test format and used to *indirectly* assess the industrial arts students' ability to perform as per the objective.

Thus, it can be seen that indirect assessments of industrial arts students' motor skills and performance can be obtained by measuring what they *know and understand* about performing the task(s) presented in the performance objective. Often, indirect assessments provide good measures of students' abilities to perform psychomotor skills. However, these assessments come with no guarantees. For example, demonstrated knowledge of key parts and their functions and understanding of the relationships between and among these parts in functioning and non-functioning faucets is no guarantee that one can perform repairs effectively, efficiently, and above all, safely. Direct assessment is the only approach that comes even close to providing valid and reliable measures of psychomotor skills.

In more graphic terms, driver education students who test out as being knowledgeable of speed limits, road signs, driving technique, and the like (indirect assessments) still must pass the driving test portion of the license examination (direct assessment) before driver's licenses are issued to them.

In this example, however, the indirect assessment does play an important role in the total examination process. It serves to protect the lives and property of both the examiner and examinee as well as other vehicle operators on the road in the immediate vicinity. It would be a very unsafe act to administer the driving test to those who had not first demonstrated indirectly adequate potential for safely performing the tasks involved. The same could be said for some skills taught in industrial arts programs.

In addition to deciding on direct or indirect assessment industrial arts educators need also to consider the focus on their assessments. In some instances it is important to focus on process and in others on product.

Process Focus

When focusing on process, if industrial arts students are able to perform adequately each *process* or step involved in a psychomotor skill or performance, then it is assumed they probably have attained the skills needed to perform as indicated in the performance objective. Again, using the foregoing leaky faucet objective, if students can demonstrate to an examiner's satisfaction that they can:

- trouble shoot faucet leaks (whatever their source might be),
- replace faucet washers,
- surface or replace eroded seats, and
- replace O-rings;

then, one could be fairly certain they had achieved the performance objective.

Pure process focus is concerned only with process and pays little or no attention to the end product that is produced as a result of the students demonstrating their skill(s). However, before an industrial arts educator could be very certain that the students had attained this performance objective, the focus of the assessment would have to be shifted to product. The end product (repaired faucet) would have to be tested to see if it performed to manufacturer's specifications.

Product Focus

When focusing on product, if students can produce acceptable end *products*, then they probably have attained the skills needed to perform as indicated in the performance objective. With a pure product focus, no consideration is given to anything except the product that is the end result of the student's attempt to demonstrate the competencies called for in the objective.

Usually, quite accurate assessments are obtained. Using the leaky faucet performance objective as an example one final time, if the industrial arts students can correctly diagnose the malfunction(s) and repair the faucet such that when the examiner puts it to the test it functions as per manufacturer's specifications, then one could be quite certain that the students had achieved the performance objective.

	PROCESS FOCUS	PRODUCT FOCUS
DIRECT ASSESSMENT	Direct/Process	Direct/Product
INDIRECT ASSESSMENT	Indirect/Process	Indirect/Product

Figure 6-1. Model for assessing motor skills and performance.

A Model

Direct, indirect, process, and product then are all considerations that should be up front for industrial arts educators as they begin thinking about assessing their students' achievement of performance objectives. The model presented in Figure 6-1 should prove useful in the beginning stages of this process.

From the discussion presented earlier and the model presented in Figure 6-1, it is apparent that industrial arts educators can choose to utilize one or more of four approaches in assessing student achievement of performance objectives; *direct process assessment, direct product assessment, indirect process assessment,* and *indirect product assessment.* Each can be used singly or in combination with others. Whichever approach(es) is/are selected, it/they should be of value in selecting or developing appropriate instrumentation.

EXAMPLE INSTRUMENTATION

The purpose of this section of the chapter is to introduce the readers to examples of the types of instruments that might be developed and used by industrial arts educators who attempt to implement any or all of the types of assessment suggested by the model presented in Figure 6-1. No attempt is made to assist readers to develop further their measurement and evaluation competencies. The restrictions imposed by the necessity for brevity here cause an in-depth treatment of instrumentation to be left to comprehensive texts written by industrial educators, i.e., Micheels and Karnes, 1950, and Erickson and Wentling, 1976. Both are good resources for techniques in developing sound instrumentation to measure student achievement in industrial arts classes.

Without the use of sound instrumentation, assessing student attainment of performance objectives is reduced to the industrial arts educator (or some other evaluator) making informal, subjective, and often unreliable and invalid assessments of student performances. Good instrumentation is critical to the measurement process. It, in itself, doesn't guarantee obtaining formal, objective, reliable, and valid measures of performance. But, it *greatly* increases the chances of doing so.

The examples that follow are intended to be just that: examples of the types of instruments that industrial arts educators can develop for use in assessing motor skills and performance in their classes. Each is related to one of the four parts of the model presented in Figure 6-1.

Direct Process Assessment

In direct process assessment the industrial arts educator would *directly* observe students as they proceeded step by step through the process of performing the task specified in a student performance objective. For example, if a performance objective calls for the industrial arts students to be able to set up an oxyacetylene welding outfit, then a procedural checklist like that presented in Figure 6-2 might be used in assessing student performance of this task.

SETTING UP THE OXYACETYLENE RIG

APPRENTICE'S ACTIONS	EVENT	CORRECT PROCEDURE
a. Cracks valves on bottles	______	______
b. Attaches regulators	______	______
c. Checks and/or relieves regulator diaphrams	______	______
d. Opens oxygen valve	______	______
e. Opens acetylene valve	______	______
f. Etc.	Etc.	Etc.

Figure 6-2. Procedural checklist for assessing student performance and correct procedure.

The checklist would contain the key steps that are to be observed by the person assessing the students' performance. Each student's actions would be *directly* observed and recorded at each step in the *process* of performing the task. The steps contained in the checklist would be the only points of observation considered in the assessment process. Any observations of other points would be set aside and not recorded. At the conclusion of the performance, the completed checklist would provide an accurate record of the steps that were followed and of the correctness of the procedure that was used at each step.

If it is desirable for the industrial arts educator to provide a *quantitative* measure of each student's performance in direct process assessment, then a numerical rating scale like that presented in Figure 6-3 might be used.

This rating scale, too, is composed of the key steps in performing the motor skill: in this example arc welding. This instrument though provides scales that have been divided into equal intervals. The intervals are in turn labeled with a descriptor and/or an associated number.

Rating scales also cause the observer making the assessment to focus attention on the key steps in the process. In addition, the descriptors offer a frame of reference for each number along the scale. The numbers can provide, in the end, a quantitative assessment of the degree to which the learners can perform as expected.

Direct process assessment is particularly useful when measuring industrial arts students' achievement of psychomotor skills or performances where (1) safety is a factor and/or (2) there is an interest in diagnosing problems that students are having in learning to perform skillfully. Direct observation of students' performance as they proceed

ARC WELDING PROCEDURES

	RATING				
Current Setting	1 Low	2	3 Correct	2	1 High
Rod Size	1 Small	2	3 Correct	2	1 Large
Length of Arc	1 Short	2	3 Correct	2	1 Long
Speed	1 Slow	2	3 Correct	2	1 Fast
Etc.	Etc.				

Figure 6-3. Numerical rating scale for quantitative assessment of student performance.

step-by-step through a formal demonstration of their skill provides the observer an opportunity to stop the demonstration if it becomes apparent that to continue would pose a threat to the personal safety of the demonstrator or others in the immediate area. Thus, it would be wise for industrial arts educators to use direct process assessment when measuring, for example, students' skill in the use of potentially dangerous hand and power tools and power equipment.

Direct observation of process also provides industrial arts educators opportunities to detect problems that students are having in developing or refining a particular skill. Often the existence of particular problems is not apparent from an assessment of the product produced at the end of a student's performance. For example, wood products that have been turned on a lathe may not reveal the techniques used, i.e., scraping and sanding versus employing more skilled cutting techniques with the lathe tools. Only direct observation of the techniques students employ in turning wood on a lathe will provide a diagnostic assessment that would be useful in helping them to become skillful wood turners.

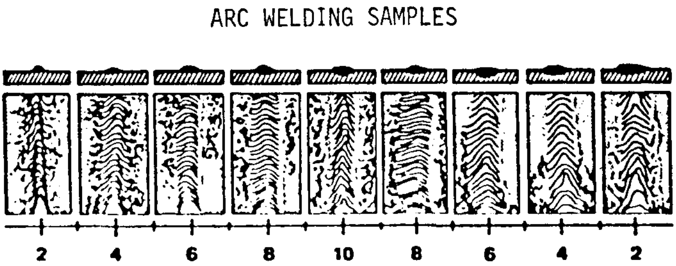
Direct Product Assessment

In direct product assessment attention is given to assessing not the process used but the product that resulted from industrial arts students' formal demonstrations of the psychomotor skills or performance in question. For example, if the performance objective calls for students to be able to construct a concrete-block wall section, then a numerical rating scale like that presented in Figure 6-4 might be used in assessing their ability to perform this task.

CONCRETE-BLOCK WALL SECTION

CHECK POINTS			RATINGS		
	Unacceptable	Poor	Average	Good	Outstanding
- Plumb	1	2	3	4	5
- Level	1	2	3	4	5
- Mortar Joints					
- width	1	2	3	4	5
- depth	1	2	3	4	5
- uniformity	1	2	3	4	5
- Etc.	Etc.				

Figure 6-4. Numerical rating scale for quantitative assessment of the product of students' performance.



ARC WELDING SAMPLES

Figure 6-5. Product rating scale for assessing students' welding skills.

Note that the rating scale is constructed so as to cause the rater to focus only on the elements that constitute a good block wall: plumbness, levelness, good joints, and the like. Descriptors ranging from unacceptable to outstanding and their associated numbers are useful in helping the rater to come up with an overall numerical rating for each product. This is particularly useful when the work of several students is to be assessed and compared. Numbers make for easy comparisons.

Product rating scales also are useful instruments when assessing industrial arts students' products. Figure 6-5 presents an example product rating scale for assessing welds made by students.

In using a scale such as this, each industrial arts student's weld would be held up and moved along the scale until one finds the scale weld that most closely matches that student's weld. The student weld, then, would receive a numerical rating equal to the scale value associated with the scale weld it most closely matched.

Product rating scales are easy to construct. The industrial arts educator can prepare or have prepared a series of like products that range along a continuum from poor to excellent. The simplest way, however, is to (1) collect over a period of time a series of actual student products that range in quality along such a continuum, (2) assign appropriate numerical values to them, and (3) fasten them in scale order to an appropriate backing material.

There are many types of industrial arts student products that reflect the level of skill employed in their development. All have potential for being incorporated into product rating scales to be used in assessing the skill of the developer. Welds are only one example. Applied surface finishes, developed photos, drafting line weights, machined finishes, and machined threads are among others that might be considered.

In addition to being fairly easy to construct, product rating scales have another advantage as an assessment tool. When posted in the laboratory, they lend themselves well to industrial arts students using them to monitor and evaluate their own progress as they work toward developing the ability to perform skilled operations and procedures. The feedback thus provided, if it is positive feedback, can serve to motivate students to improve their performance as they continue to move farther up the rating scale with their products.

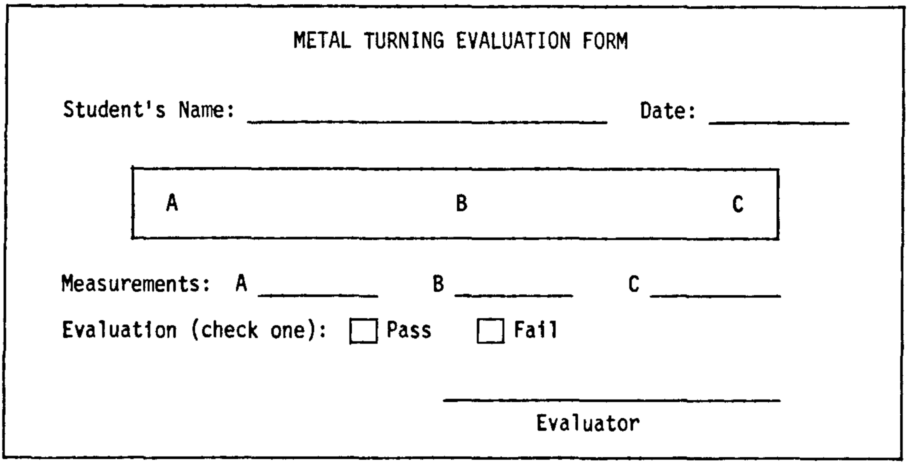
Other product focused techniques for directly assessing student achievement of psychomotor skills and performance include destructive and nondestructive methods of testing products. Examples of the former include welding bend, pressure, and tensiletests and similar tests for student developed products that mutilate or destroy the product. Examples of the latter include x-raying welds; energizing electrical circuits; running computer programs; testing radios; TV's, motors, and engines; and the like.

Whether the testing procedures be destructive or nondestructive, it is important to note that passing or failing should be based upon appropriate objective criteria that are made known to the industrial arts students, preferably at the time instruction begins and as a part of the student performance objectives for that instruction. For example, the following objective makes quite clear the level of proficiency that will be expected in order for the students' products to pass the testing procedure:

> *Given the appropriate tools, equipment, and materials in the laboratory, the students will be able to turn stock on the metal lathe to within ±.003" of a given dimension.*

Assessing student achievement of this objective would employ a nondestructive technique. The diameter of each student's completed product would be measured using a micrometer (or some other suitable instrument) in a selected number of places along its length. If all of the measurements are within the stated tolerance (± .003"), then the product and the student pass. If not, then the product fails and the student is judged as not having achieved this psychomotor performance objective.

Instrumentation to be used by industrial arts educators to assist them with destructive and nondestructive testing of students' products is very different from those described earlier in this chapter. For this type of product assessment, the industrial arts educator can usually employ measuring instruments that provide physical measurements of the degree to which the product meets the stated criteria. Micrometers, scales, protractors, go-no-go gauges, materials testing machines, and the like will be the types of instruments used. They will provide objective, reliable, and very precise data in the form of linear distances, weights, degrees, pounds per square inch, and the like.



METAL TURNING EVALUATION FORM

Student's Name: ______________________ Date: __________

A B C

Measurements: A ________ B ________ C ________

Evaluation (check one): ☐ Pass ☐ Fail

____
Evaluator

Figure 6-6. Evaluation form for nondestructive testing of students' products.

To insure that the instruments are applied to individual student products in the same manner, some form to standardize the measurement process should be developed and utilized by the industrial arts educator. For example, in assessing student achievement of the foregoing lathe turning objective, an evaluation form similar to that presented in Figure 6-6 might be used.

Having a form like the metal turning evaluation form presented in Figure 6-6 attached to each student's product helps to insure that all and only the prescribed measurements will be taken and used in the evaluation process. It also serves as a good place to record the measurements taken, the evaluation decision, and the name of the evaluator, right along with the student's name and the date. Moreover, if carbon paper is used, then student and teacher copies can be made at the same time and student copies can be distributed immediately thereafter, if appropriate.

Thus far only the top portion of the performance assessment model presented in Figure 6-1 has been defined and explored herein. Although fewer than those of the top portion, the bottom portion of the model also has some implications for assessing motor skills and performance in industrial arts education programs.

The bottom portion of the model is concerned with *indirect* assessment. And like direct assessment, the model indicates that indirect assessment can take two focuses: process and/or product.

Indirect Process Assessment

In indirect process assessment, one is really assessing the knowledge and understanding of the process(es) involved in demonstrating the proficiency needed to perform a selected psychomotor skill. The knowledge and understanding assessed could relate to any number of things including: (1) the tools, materials, and equipment used, (2) the sequence and the procedures used, (3) the relationships between and among such process variables as time, temperature, speed, feed, hardness, density, and successful performance, and (4) the safety precautions to be observed for a safe performance.

Indirect assessment (both process and product) has some underlying assumptions. One is that students who can demonstrate satisfactory knowledge and understanding with respect to some particular motor skill or performance are assumed to be capable performers as well. For individual students this may or may not be a valid assumption. However, industrial arts educators could quite safely assume that those of their students who could not demonstrate adequate knowledge and understanding of the foregoing types with respect to some particular motor skill or performance also could not adequately demonstrate that skill or performance in a direct assessment. For example, indirect process assessment would seem to be an extremely appropriate technique, to initially assess industrial arts students' readiness to use, with little or no direct supervision, tools and equipment that harbor potential dangers for unskilled and/or careless users.

In instances where safety is of very little or no concern and direct assessment is impractical or impossible, indirect assessments may be a good substitute for directly assessing student achievement of motor-skills-oriented performance objectives. Well developed indirect assessments can serve as good substitutes for direct assessment techniques, but indirect assessment should never be thought of as a total replacement for direct assessment. The *only way* industrial arts educators can be even near certain that students have achieved the motor-skills-oriented performance objectives set forth in their classes is to use direct assessment techniques when assessing these objectives.

An industrial arts class, for example, might have as an objective one similar to the following:

> *Given access to the appropriate tools, materials, and equipment, students will be able to square stock to within ± 1/16" and 3° of given dimensions.*

The preferred way to assess achievement of this objective would be to use a direct assessment of process, product, or both. However, if it was decided that an indirect process assessment would be used, then the industrial arts educator could proceed to develop a measurement instrument that would focus on the knowledge and understanding that is key to performing as per the objective. For example, if there was an emphasis on woodworking in the class, then items like those presented in Figures 6-7 and 6-8 might be used.

Test items like those presented in Figures 6-7 and 6-8 would be useful in making direct assessment of *knowledge* and *understanding* of the process(es) involved in squaring boards to a given dimension and an indirect assessment of the ability to perform as per the foregoing objec-

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Which of the following procedures is the first step in squaring a board to a given dimension?

a. Cut it to appropriate length
b. Surface one side to flat
c. Cut it to appropriate width
d. Plane one edge straight

Figure 6-7. Objective test item for assessing understanding of process (and indirectly, performance).

In the spaces provided below list the steps one would use in machining a rough-cut board measuring approximately 1 x 10 x 70" to a squared board measuring 3/4 x 8 x 37".

(1) ______________________________

(2) ______________________________

(3) ______________________________

(4) ______________________________

(5) ______________________________

(6) ______________________________

(7) ______________________________

Figure 6-8. Constructed response type test item for assessing knowledge of process (and indirectly, performance).

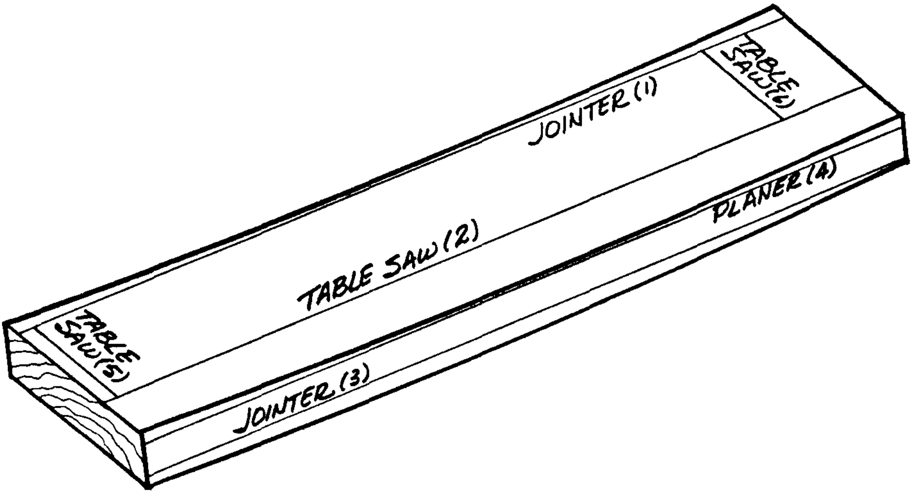

Figure 6-9. Example student product developed in response to a simulation test to assess knowledge of process (and indirectly, performance).

tive. Again, one must keep in mind that demonstrated knowledge and understanding do not always equal the ability to demonstrate the psychomotor skill or performance.

The other indirect approach that could be used in assessing achievement of this objective is indirect product assessment. How does one indirectly assess product?

Indirect Product Assessment

Indirect product assessment for the foregoing squaring stock objective could use a simulation test. For example, each industrial arts student to be tested could be given a board measuring 1 x 10 x 36″ and asked to (1) draw on it (using a T-square, rule, and pen) the lines where cuts would be made, (2) number the order in which the cuts would be made, and (3) label each line with the name of the machine to be used to make each cut when squaring that board to the dimensions 3/4 x 6 x 28″. Figure 6-9 presents a rendering of what the completed simulation might look like.

The industrial arts educator would, in this example, check each product for correct (1) line placement, (2) dimensions, (3) machine label, and (4) sequence of simulated machine operations. As in direct product assessment, instrumentation to assist the industrial arts educator to focus on the criteria for scoring this simulation test should be developed and used. An example is presented in Figure 6-10.

SIMULATION TEST SCORING FORM

SQUARING BOARDS TO DIMENSION

Name ______________________________ Date ________________

ASSESSMENT CRITERIA	QUALITY POINTS POSSIBLE	QUALITY POINTS AWARDED
A. Machining lines correctly positioned.	6	___
B. Dimensions correct.	6	___
C. Machining operations correctly labeled.	6	___
D. Machining operations correctly ordered.	6	___
TOTALS	24	___

Figure 6-10. Form for scoring simulation test for indirect assessment of students' products.

In using the scoring form presented in Figure 6-10, the industrial arts educator would apply the indicated assessment criteria to each student product to be assessed and subtract from the indicated points possible one point for each error made by the student. The points to be awarded, then, would be recorded and summed in the column provided on the far right side of the form.

Simulation tests offer considerable potential for indirect product assessment of the degree to which industrial arts students have achieved motor skill and performance oriented student objectives. Breadboard simulations in testing electricity and electronics skills, machining styrofoam in testing machine metals skills, pouring low-melting point metals in testing casting skills, and developing and cutting paper patterns in testing sheetmetal developmental skills are but a few examples of simulations being used to provide products for indirect assessment of student achievement of motor skill and performance oriented student performance objectives.

IMPLICATIONS FOR INDUSTRIAL ARTS PROGRAMS

Industrial arts educators should recognize the important role that their programs can play in assisting students to develop psychomotor skills, many of which will be important to them throughout life in their roles as wage earners or other workers, homeowners, consumers, avocational craftsmen, and hobbyists. While certainly not the program's *raison d'etre*, assisting students to develop psychomotor skills and the ability to perform well in various tools and materials oriented environments is one of the unique aspects of industrial arts education. No other curriculum area in public school education can lay claim to stimulating and serving this area of student growth and development to the degree that industrial arts programs do.

To better clarify this aspect of the industrial arts program and to better measure the degree to which they are successful in this role, industrial arts educators should develop and use good student performance objectives. These objectives should specify the types and levels of motor skills and performances they are attempting to develop through their programs. As indicated earlier, these objectives should contain condition, task, and criterion statements.

In this format they will not only communicate well the intent of the industrial arts program, but will serve as the basis for assessing student attainment of the types and levels of learning expressed within them. One of the most difficult aspects of measurement for all educators is in deciding specifically what to measure. Good student performance objectives (whether they focus on knowledge, understanding, affective behaviors, or psychomotor skills) certainly minimize and often erase that difficulty.

Industrial arts educators consistently have done a better job of identifying, teaching, and assessing knowledge and understanding than they have done with motor skills and performance. Since the latter two are such important elements of the industrial arts program, it is important for industrial arts educators to give them a level of attention that is at least equivalent to that currently enjoyed by the former two. Assessment for any one element of the program should neither be ignored nor left to informal processes. Industrial arts educators owe it to the program, students, parents, and administration to make valid assessments of student growth and development in *all* areas of learning — cognitive, affective, and psychomotor.

Those who experience difficulty in obtaining or developing good industrial arts student performance objectives for each of the foregoing areas of student growth and development should seek immediate assistance. Assistance can come from a variety of sources including in-service workshops and courses conducted by appropriate university teacher educators. However, materials published by professional associations, textbooks, published curriculum materials, and course materials prepared and used by other industrial arts educators all are sources of information, understanding, and techniques that would be helpful in a personal program of professional renewal. Included in the references cited at the end of this chapter are publications that industrial arts educators will find particularly useful in such a renewal process.

IMPLICATIONS FOR INDUSTRIAL ARTS TEACHER EDUCATION

Certainly all industrial arts teacher educators recognize the importance of psychomotor skills and performance as products of elementary, secondary, and post-secondary industrial arts programs. They also recognize the importance that development of motor skills and the ability to perform have for industrial arts teacher education programs. For two reasons it is particularly important that industrial arts teacher educators do an exemplary job of teaching and assessing appropriate motor skills and performance.

First, the profession wants to graduate and certify to be industrial arts educators only those who are safe and skillful in the use, operation, and maintenance of tools, materials, and equipment in industrial arts laboratories. This means that industrial arts teacher educators must develop and use valid techniques for measuring their students' motor skills and performance with the tools, materials, and equipment commonly found in industrial arts laboratories and drafting rooms. To do less would be considered inappropriate, if not irresponsible, on their part.

Second, teachers do tend to teach as they were taught. Therefore, industrial arts teacher educators should use in their classes exemplary techniques. For example, objectives for their instruction should be student performance objectives which include condition, task, and criterion statements; their instruction should be directed toward these objectives; and their assessments of students' learning should be based upon and at least sample all the instructional objectives.

In short, in their laboratory classes industrial arts teacher educators should be using (1) sound student performance objectives that focus on the psychomotor skills needed to perform proficiently as an industrial arts educator and (2) valid techniques for assessing achievement of these objectives. Industrial arts teacher education students will then be able to experience and see the value that performance objectives and good assessment techniques hold for teaching and assessing psychomotor skills and performance. In addition, this experience will motivate them and assist them to learn in their *methods* classes how to prepare good student performance objectives and measure achievement of those objectives.

Industrial arts teacher education programs that are not placing adequate emphasis on procedures and techniques for developing and assessing student achievement of skill and performance oriented student performance objectives should be doing so. The development of selected psychomotor skills is an important part of industrial arts education and all students' growth and development. Industrial arts educators must be prepared to guide this growth and development and to assess the degree to which anticipated change has been realized by each student enrolled in their classes. Industrial arts teacher education programs have a responsibility to provide for their students effecive pre- and in-service experiences in assessing students' psychomotor skills and performance with emphasis on direct and indirect assessments with product and process focuses.

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Chapter 7

Instructional Strategies in the Teaching of Perceptual and Psychomotor Skills

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This chapter is written from the perspective of a practitioner and developer of psychomotor skills instruction. It is intended to provide some measure of guidance to those who are engaged in educating youngsters in the acquisition of psychomotor skills.

There are so many factors which can be considered when constructing a strategy for teaching psychomotor skills that the teacher or developer who attempts to consider all of them will most likely become paralyzed and be unable to proceed. For this reason, several important factors have been chosen for presentation in this chapter. Even though the universe of factors has been narrowed, the reader will find the factors presented to be somewhat complex and requiring study.

The first section of this chapter suggests three factors for teachers to consider prior to deciding upon an instructional strategy. The second section presents five phases that should be incorporated into an instructional strategy. Examples of the five phases are also presented in the second section in order to provide the reader with applications of recommended principles.

FACTORS TO CONSIDER PRIOR TO DESIGNING PSYCHOMOTOR INSTRUCTION

Prior to designing instruction for psychomotor skills, a teacher should: analyze the skill and design the sequence of instruction for the skill, determine whether the demonstration or discovery approach is more valid, and select a means to motivate the student to learn the skill. It is suggested that a teacher give ample consideration to these factors prior to embarking upon the design, development and implementation of an instructional strategy. In effect, addressing these factors is a necessary prerequisite to designing an instructional strategy.

Analyzing the Task and Sequencing Instruction

Prior to embarking upon the development of an instructional strategy, the teacher must clearly define the skills he or she wishes to teach and must also define the interrelationship of those skills. This section focuses upon some strategies for addressing these issues. While the section relies heavily upon cognitive research, this author has found the techniques to be effective in the psychomotor domain.

Singer and Pease (1976) have pointed out the importance of teachers specifying the objective of a learning exercise, that is, specifying the objective for learning new materials or skills. Mager (1962) and Vargas (1972) have also argued for the delineation of clearly defined behavioral objectives. They suggest that the absence of such goals or objectives makes it difficult to efficiently evaluate a course or learner outcomes, to select instructional methods. Popham (1969) presented eleven arguments against behavioral goals but concluded his review by stating

> . . . when we are attempting to promote the wide-scale adoption of precision in the classroom, there is danger that many instructors will use the comments and objections of these few critics as an excuse for not thinking clearly about their goals. Any risks we run by moving to behavioral goals are miniscule in contrast with our current state of confusion regarding instructional intentions (p. 72).

To be valid, an industrial education program requires a strong relationship between the skills taught in a program and the need of industry for such skills. It is therefore essential that the technical and vocational objectives be derived from the needs of industry and the job tasks expected of those entering the world of work. Herschbach (1979) has recommended that technical and vocational objectives should be the translation of job tasks into learning outcomes. He suggests that valid linkages between the expectations of the workplace and technical objectives are necessary for effective instructional programming.

Herschbach (1975) has presented an excellent guide to constructing performance objectives in the psychomotor domain. He utilizes Simpson's (1966) major categories of the psychomotor domain — perception, set, guided response, mechanism, complex overt response, adaptation and origination — and presents a method for constructing objectives for the seven categories of the domain. He presents example infinitives along with example direct objects for each of the major categories. For example, the infinitives "assemble and calibrate" are presented along with the direct objects "parts and materials" for the category "mechanism." The behavior "assemble a part" could therefore be specified for the psychomotor category of "mechanism." A developer of instruction can utilize Herschbach's guidance and apply the A-B-C-D method for specifying psychomotor objectives. That is, an objective should specify the *audience* who is to exhibit a behavior, the *behavior* (infinitive and object) to be exhibited, the *conditions* under which the behavior is to be exhibited and the *degree* of proficiency expected when the behavior is being exhibited.

Shemick (1977) has contributed further to our capability to classify psychomotor objectives by delineating sixteen hierarchically ordered types of skilled tasks elaborating upon Fitts and Posner's (1969) work. His taxonomy is very useful for guiding the classification of research that can eventually be translated into useful recommendations for instructional purposes. Simpson's taxonomy is, however, recommended for use by this author for teachers and developers of instruction. Specifying objectives in the fashion detailed above can lead to a set of terminal psychomotor competencies that are expected of a student and tied to requirements of the workplace.

Teachers who are attempting to facilitate the learning of a terminal psychomotor competency must concern themselves with the student's capability to perform the prerequisites or enabling competencies for the skill; i.e., the teacher is faced with determining the enabling competencies for a terminal psychomotor skill. Gagné (1968) proposed a theory of hierarchies of skills, hypothesizing that there are higher order skills that can be learned only after the acquisition of a series of lower order skills. A hierarchy of such skills is constructed by stating the terminal skill or capability and asking, "What would the individual have to know how *to do* in order to *perform* this task, after being given only instructions?" (Gagné, Mayor & Paradise, 1962, page 1). This type of logical analysis tends to produce a pyramid of skills with the highest order terminal skill at the top and the lower order skills toward the bottom.

Research on hierarchies (Gagné, 1962; Gagné, et al., 1962; Gagné & Paradise, 1961; Merrill, Barton & Wood, 1970; Novillis, 1976; Phillips, 1971; Phillips & Kane, 1973) indicates that new skills are derived from lower order skills and that instructional materials which reflect a hierarchy demonstrate the most probable expectation of greatest positive transfer. The hierarchical validation research has, however, been conducted primarily in the subject matter areas of science and mathematics (Gagné, 1962; Gagné, et al., 1962; Novillis, 1976; Phillips & Kane, 1973). If one were to view the sciences and mathematics from a purely intuitive perspective, there is an inherent logical structure to the content. This logical structure has been supported by the hierarchical validation research. Technical disciplines are directly derived from the disciplines of science and mathematics and are the application of these disciplines to practical physical problems. It, therefore, seems appropriate to assume that subject matter in technical fields, including psychomotor skills, can be arranged in hierarchies of skills in the same fashion as in the sciences and mathematics. A summary of the technique Gagné developed and used for positing and validating a hierarchy is as follows (adapted from White, 1974):

1. State a task in behavioral terms (see the discussion in the Strategy section of this chapter).
2. Derive elements subordinate to the task by asking of each element in turn, "What would the learner have to be able to do in order to learn this new task, given only directions?"
3. Write a learning program to teach the elements of the derived hierarchy.
4. Have a number of students work through the learning program.
5. Test the students on their achievement of the elements.
6. Summarize the results of the test by reporting, for each connected pair of elements, the numbers of students in four categories: those who learned both elements, those who learned neither, those who learned the upper element only (i.e., whose behavior was contrary to that predicted by the hierarchy), and those who learned the lower elements only.
7. Remove from the hierarchy those connections between elements where the numbers of students who learned only the upper element appear to be too large to have arisen by some chance effect.

One problem, which the above model does not address, is the practicality of applying such a method in the development of instruction. It is clearly beyond the 'call of duty' to expect a teacher to implement such a process in preparation for instruction. If such a process were faithfully followed by teachers for all skills taught, there would be little time for much else. The model cited above is exacting and is more appropriate for purposes of research than for purposes of developing instruction. A simplified model for *instructional purposes* is therefore recommended (DeCaro & Blake, 1980):

1. Define in behavioral terms, the psychomotor skill which is to be the terminal (final) task in the hierarchy (Herschbach, 1975).
2. Derive the hierarchy by asking Gagné's question ("What must the learner be able to do in order to learn this new element,

given only directions?") for each element in turn, from the terminal element downward. Include all skills that seem reasonable since the validation process can only disprove postulated connections, not create them.
3. Check the reasonableness of the postulated hierarchy with experienced teachers and subject matter experts. This can be accomplished by doing one or more of the following: (a) having them critique the posited hierarchy, (b) giving them the elements and having them draw the connections, and (c) having them perform the terminal task and observing them.

Having completed this type of analysis the teacher has a 'skill road map' of the prerequisite competencies for the psychomotor skills to be learned. It should be pointed out here that the elements of the hierarchy will not all be psychomotor skills. Herschbach (1975) has pointed out that a psychomotor task will necessarily subsume cognitive elements as well as affective elements (willingness to perform the task). For example, prior to being able to perform many psychomotor skills at a lathe, a student must be able to perform certain prerequisite mathematical manipulations and computations. Such skills are clearly a prerequisite to executing certain psychomotor tasks correctly.

Once teachers understand the hierarchical organization of the skills to be taught, they are faced with a dilemma — how to sequence the instruction. DeCaro & Blake (1980) have suggested a methodology for sequencing instruction in accordance with a validated hierarchy of skills. Their technique assumes that an upward sequencing of instruction is appropriate. This may be true for a complex skills hierarchy but may not be so for a hierarchy for which students possess a significant number of the skills. Since the teacher of psychomotor skills in industrial arts education is involved, more often than not, in teaching a terminal skill for which learners do not possess the prerequisite skills, DeCaro & Blake's technique is appropriate to use as presented below. The teacher who determines that a down-the-hierarchy order is more appropriate for certain students may simply invert the order that would be derived by using the following technique:

1. Using a knowledge of learner characteristics, determine whether remedial tasks or enrichment tasks should be added to the hierarchy.
2. Draw a circle around a group of three to seven tasks in the hierarchy (Miller, 1956) that will require about fifteen minutes for learning. The boundary line should not encompass a super-

ordinate skill whose subordinate skills have not been encompassed. The skills encompassed by a circle will be called a cluster.

3. Repeat steps one and two above until all the skills have been circled (See Figure 7-1).
4. Number each cluster of skills in a sequence, from bottom to top, so that no superordinate cluster precedes a subordinate cluster in sequence.
5. Number the skills within each cluster so that no subordinate skill follows a superordinate skill.
6. Sequence the instructional materials in the numerical order derived in steps 1-5.

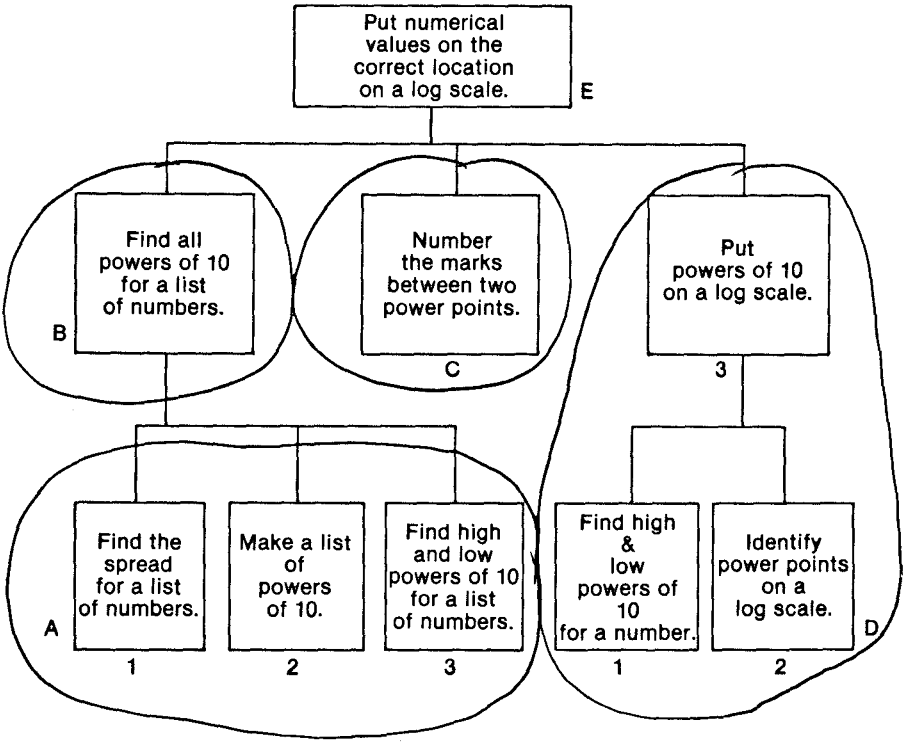


Figure 7-1. A hierarchy of skills for placing data on a log scale.

Demonstration versus Discovery

When teaching the skills in a hierarchy, the teacher can use an instructional strategy that is expository in nature (demonstration) or one that is inductive in nature (the discovery method). One can find adamant proponents of each method in education, with the debate reaching back to ancient Greece. The literature reviewed by this author indicated that rigid adherence to any one method is not appropriate. Differing circumstances require differing approaches to instruction — exposition or discovery. There are three variables that teachers may wish to consider as they determine which approach to use: the difficulty of the task, whether transfer is a desired outcome, and whether or not the skill to be learned is open or closed loop in nature. These variables are described below.

Difficulty of the task. Danner (1974) conducted research in an effort to examine the differences between the discovery and expository methods (demonstration) of instruction. Analysis of the data gathered in the study indicated that one of the lessons used in the experiment was more difficult than the other. The investigator found that the demonstration method was more beneficial for the lesson of greatest difficulty. It was further found that the discovery method was more useful for the less difficult lesson. Blake (1980) in a review of the literature of demonstration versus expository instruction suggested that the demonstration approach would be more effective than the discovery method if a learning task is difficult and if it is difficult for the student to discover the rules governing the skill. Danner's research study would tend to suggest that the converse is true for the discovery method.

Singer & Pease (1976) found that learners receiving guidance enjoyed a significant advantage over those learners receiving no guidance in early learning trials of a psychomotor task. They indicated that the "guided learners maintained this advantage throughout the twenty initial learning trials. The need for a greater than usual number of learning trials can be explained by the complexity of the present task as compared to the tasks used in other studies" (p. 793). This would tend to suggest that demonstration is more efficient for teaching complex skills while the discovery method is more appropriate for skills that are not complex. It is important to point out here that complexity is a variable that should be functionally defined in accordance with the capabilities of the learner. Skills that would be classified as complex for the unsophisticated learner would not be very complex for the skilled learner. While an apprentice machinist may find a new skill quite complex, the experienced machinist might find the same skill to be quite simple.

Transfer as an outcome. If a skill which has been learned is to be applied in new situations, the literature suggests that the discovery method may be more appropriate than the demonstration method (Singer & Pease, 1976; Pease, 1975). In examining the effect of demonstration versus discovery strategies on the transfer of a psychomotor skill, Pease (1975) found that the students whose transfer task matched the instructional strategy performed best. Singer & Pease (1976) added to our understanding of the effect of demonstration and discovery on performance of a transfer task when they utilized three strategies to teach a psychomotor skill: a guided strategy (demonstration type), a discovery strategy and a combination guided-discovery method. The investigators found that the learners who received the combination strategy were more efficient timewise in the initial learning than was the discovery group and were also equal to the discovery group in transfer to new situations and retention.

The literature suggests that demonstration is more appropriate for the initial learning trials of a new skill. Once the learner has developed some minimal level of competency in performing the skill, it is appropriate to utilize the discovery method and have the student apply the skill in unencountered situations in which the skill is needed. This approach can provide efficiency in the initial trials while the student is learning the competency and also facilitate transfer to new situations.

Open- and closed-loop skills. Braverman & DeCaro (1979) have suggested that the nature of the skill to be learned (open- or closed-loop) is a critical variable in determining the instructional method to be used. Adams (1971) posited two mechanisms for motor skill acquisition. He developed the concept of open- and closed-loop aspects of motor development as follows:

1. An open-loop skill has no feedback or mechanisms for error regulation until the termination of the task. The movements required of such a skill are so rapid that corrective feedback cannot be processed. In such a system, the input events exert their influence, and the system has an output. Such skills are usually externally paced and behavior must be adapted to a continually changing situation. A batter hitting a baseball is an example of an open-loop skill.

2. A closed-loop skill has feedback, error detection and error correction as key elements. The requirements of such an activity are predictable and the activity is usually self-paced. An example of such a skill would be found in using a lathe to turn down a piece of bar stock.

Singer (1977) has suggested that the appropriateness of instructional strategies depends upon whether an open-loop or closed-loop skill is to be learned. He suggests that heavily guided learning is the most expedient way of achieving learning goals for closed-loop skills. On the other hand, for activities that will place unpredictable response demands upon a learner, he suggests that learning experiences in a variety of environments or a discovery-oriented approach is most appropriate. In the learning of machine use skills, many initial learning tasks tend to be of the closed-loop variety. Learners must first develop a repertoire of appropriate behaviors in order to be able to correctly execute the rapid movement in the absence of feedback required of an open-loop skill. For example, prior to being able to apply a bolt with an air wrench the learner must first be able to perform the component tasks associated with the activity. Learners must perform the sub-skills (closed-loop) proficiently and automatically. That is, they must be able to load the wrench, apply the socket and grip the wrench. This makes it possible for learners to focus upon the superordinate problem of applying the bolt. In effect, the component skills can be classified as closed-loop skills while the task of applying the bolt can be classified as an open-loop skill. The component tasks in the example above are valid ones for a learning situation and each requires a different instructional strategy. The closed-loop skills require a heavily guided strategy with continuous feedback to the learner regarding the correctness or incorrectness of responses. The overall task of applying the bolt might be more appropriate for a discovery-oriented approach where the learner attempts to apply a bolt several times using the same component task operations.

Summary. The instructor who is having students learn psychomotor skills can use discovery, demonstration or combination discovery-demonstration strategies. Singer (1977) has articulated the appropriate use of these options very well in his review of instructional strategies in psychomotor instruction. He suggests that (adapted here from Singer, 1977):

1. A guided or prompted method of learning is the most appropriate choice of instructional strategy if economy of time is important and if the only purpose of instruction is acquisition of proficiency in the skill.
2. The discovery strategy should be utilized if the goal of the learning exercise is transfer to a new and previously unencountered situation.
3. Closed-loop skills should be taught using a guided instructional strategy.
4. Open-loop skills should be taught using a discovery instructional strategy.

5. The instructional method that best approximates the environmental conditions under which the skill will be exhibited at a future date should be used.

For complex motor skills, it is often the case that the skills learned will need to be exhibited in previously unencountered situations. Suggestion two above would tend to indicate that a discovery approach would therefore be most appropriate for instruction. The skills learned in industrial arts are usually of such a complexity, however, that it would take a learner an inordinate amount of time to discover how to perform them. In addition, the learning of complex motor skills associated with machine use can be hazardous. For these reasons, a *combined* method (Singer & Pease, 1976) is suggested for the teaching of complex motor skills of the type learned in industrial arts education. The combined method consists of guiding students during early trials and fading the guidance over successive trials until the student is exhibiting the skills in new situations in the absence of prompts or cues, i.e., in a "guided discovery setting." Teachers will need to use their knowledge of learners' capabilities when determining whether to use demonstration or discovery methods of instruction. Table 7-1 can be used as quick reference by a teacher after the skills to be taught have been analyzed and the complexity of the skills for learners has been determined.

TABLE 7-1
SUMMARY OF RECOMMENDED STRATEGIES

Category	Recommended Strategy
Easy skill for the student	Discovery instructional strategy
Difficult skill for the student	Demonstration instructional strategy
Open loop skills	Discovery instructional strategy
Closed loop skills	Demonstration instructional strategy
Transfer of the skill desired	Demonstration for the early learning trial but discovery for later trials
Skill exhibited later under same conditions as when learned	Demonstration instructional strategy

Motivation to Learn Psychomotor Skills

One very important yet often overlooked factor in psychomotor instruction is the motivation of students to learn the skills and the variety of learning environments that can foster motivation. Motivation in human learners is a complex subject and cannot be covered adequately in a treatment such as this. There are, however, some suggestions gleaned from the literature which can be very useful to the teacher engaged in psychomotor instruction. Gagné (1977) has identified three attentional sets in the realm of motivation: social, task oriented and achievement oriented.

A learner may develop learning readiness that is primarily social in nature. Gagné (1977) suggests that socially oriented students engage in learning to fulfill affiliative needs — the desire to gain approval, avoid disapproval and/or establish themselves in a position of esteem among their peers. A learner may, for example, choose to develop skills in cooking in order to gain the approval of his or her peer groups, parents or teachers. However, it has been pointed out by Ausubel (1968) that social motivation or learning readiness is not a very stable factor on which to base learning. He suggests that task orientation and achievement motivation are much sounder grounds for learning. Most, if not all, humans strive for the achievement of competence in some area whether it be auto mechanics, cooking, or writing.

Competence can be achieved by the individual while functioning autonomously, competitively or cooperatively (Stinson, 1980). A learner may come to an instructional setting with a propensity to function in one of these three fashions. The student may prefer to work alone and compete with him/herself or may prefer to work alone and compete with others. On the other hand the student may prefer to work cooperatively with others in the acquisition of competence.

Many psychomotor tasks require autonomous work while others demand a certain level of cooperation. The student working at a drill press is engaged in a relatively autonomous activity. On the other hand, the individual engaged in pulling an engine block from a sports car is engaged in an activity that requires autonomous as well as some measure of cooperative actions. There are other tasks such as shooting baskets from the foul line on a basketball court during a game where the individual is clearly a member of a team and must cooperate. He/she is also in competition with the other team to score the most points.

Clearly, psychomotor skills are exhibited in settings where workers need to function autonomously, competitively or cooperatively. It therefore follows that skills should be developed in an educational environment that provides a balanced exposure to the three different motivational orientations.

For autonomous learning situations, a series of expected goals or outcomes can help to focus student attention on the task at hand (Slavin, 1977; 1978; 1980). The goals may be teacher generated goals, but the teacher may contract with the student for the time to achieve the goals or could also negotiate the specifics of the goal (Stinson, 1980); e.g., tolerance limits for three successive trials at turning down a piece of bar stock could be negotiated.

For the cooperative learning situation Stinson (1980) has suggested that students can be broken into groups to perform a project. When the project is evaluated, the same project grade could be assigned to each student. The same goal-setting strategies described above can be operationalized in the cooperative learning situation but with the goals and expectations being group goals rather than individual goals. The cooperative learning setting can foster interpersonal interaction and group problem solving.

The competitive learning environment is one that most students have frequently encountered. For example, the grading and assessment of performance using standardized tests and norms can foster competition since students are compared with other students. Grading on a curve is another strategy that can foster a competitive learning environment. These strategies can be contrasted with assessment of performance based upon pre-specified criteria. In such an assessment, the evaluation of performance is not based upon how well a student does in comparison to other students but rather how well he or she performs the required skills. A competitive environment can result in students becoming too preoccupied with competition and losing sight of the goal of the educational exercise — learning skills. Competition is, however, a fact of life in the world of work, and students need to develop strategies for coping productively with competition. Stinson (1980) has suggested that teachers can establish criteria for a grade of *C* that all students must achieve. Grades of *B* or *A* could then be assigned on a competitive basis. This strategy has the effect of ensuring some minimum level of performance without the anxieties associated with competition.

Karnes (1962) cites work which indicated that neither competitive nor cooperative learning experiences were found to be superior for the acquisition of skill in technical drawing. Tendencies in favor of cooperative learning experiences were found regarding attitude, however. This finding provides further support for the contention that an educational environment should provide an exposure to the three different motivational orientations.

As was pointed out earlier, a teacher could use all three of these strategies in the development of skills over the school year. The balanced application of these modes guarantees that students will encounter situations in which they feel comfortable and encounter situations in which they are challenged. Such a balanced application also provides exposure to the modes in which students will need to perform in the work world. It should be pointed out that for some tasks it is easier to generate an autononous learning setting while for other tasks it may be easier to generate a competitive or cooperative setting.

Wlodkowski (1978) has suggested that student motivation must be considered at the *beginning* of a learning exercise, *during* a learning exercise and when *ending* a learning exercise. At the beginning of an exercise the student *attitudes* toward the subject, teacher and learning environment should be taken into consideration. If a student initiates a learning exercise with high anxiety about the subject being studied, it is likely that he or she will not be able to perform to the best of his or her ability. During the learning exercise, it is important to *stimulate* student interest and attend to student *affective* behaviors. When ending a learning experience, it is important to provide the student with positive reinforcement and insure a measure of student success in achieving or partially achieving the goals of the exercises. The teacher wishing a full discussion of strategies for facilitating student motivation are referred to Wlodkowski's (1978) book on motivation and teaching.

A STRATEGY FOR TEACHING PSYCHOMOTOR SKILLS

As has been pointed out in the preceding section, there are some broad factors which a teacher should consider prior to deciding upon an instructional strategy. Once these factors have been given due consideration and the issues which surround them are resolved to the satisfaction of the teacher, it is appropriate to contemplate development of an instructional strategy for delivering the content to the students.

DeCaro and Blake (1980) have suggested five phases of instruction that transcend content, type of skill to be learned and mode of delivery, and which they recommend should be present in a teaching strategy:

1. An *orientation phase* in which the learner is provided an overview of the learning activities.
2. A *presentation phase* in which the learner is exposed to information or skills which must be mastered.
3. A *practice phase* in which the learner is given the opportunity to apply (practice) what he/she is learning; first with and then without assistance.

4. A *review phase* in which the learner is allowed to review what has been learned, especially if some time has elapsed since he/she learned it, and
5. An *assessment or evaluation phase* in which the learner is required to demonstrate mastery of the skills he/she has been attempting to learn.

They suggest that the instructional phases should occur as five distinct segments, but the order of the segments may vary. Presentation and practice are often integrated; for example, a skill is demonstrated to a learner who immediately practices it before proceeding to another presentation and practice segment. In a single lesson, a student may see several demonstrations (presentations) each of which is followed by a practice exercise. That is, the instructor could demonstrate the subordinate skills in an up-the-hierarchy sequence and have the student practice each skill after it is demonstrated. Sometimes, practice precedes presentation; this occurs in 'inductive' (discovery) learning. As has been pointed out previously, whether presentation precedes practice should depend upon the type of skill (open or closed) and the desired outcome of the instruction. Finally, review may occur at several points, after a single presentation or practice segment, or after a series of presentation and practice segments. Review is especially useful to help the student distinguish between similar behaviors that have been recently learned.

Orientation

The first stage of an instructional strategy should be an orientation phase. A major purpose of the orientation is to help learners focus their attention upon the knowledge or skills to be mastered (Frase, 1968; Frase, 1970; Rothkopf, 1968; Rothkopf, 1970; Faw & Walter, 1976). Expectations should be clearly stated, especially how students will be evaluated. This is often done by providing statements of competencies or objectives (Kaplan & Rothkopf, 1974), but may also be accomplished by describing or showing them a sample test. It is during the orientation stage that learners should be exposed to such pre-instructional strategies as pretests (Frase, 1970), behavioral objectives (Tyler, 1950), and overviews and advance organizers (Ausubel, 1963). For a comprehensive review of these strategies the reader is referred to Hartley & Davies (1976). Since a learner will come to the instruction possessing a variety of the skills to be learned or having very closely related skills or experiences, pre-instructional strategies can have the effect of mobilizing "motor programs" (Keele, 1968) that relate to new skills.

During the orientation phase the learner should be provided with the rationale and benefits for learning the content. The students should also be presented with the relationship of the skills they are learning to their curriculum of study. This helps to establish the salience of a skill in the overall scheme of a content area. Example applications of the skills in the world of work can often help to establish the reason for learning the skills.

Students should also be provided with explicit policies and administrative procedures for a learning exercise during the orientation. This can act to promote the smooth administration of the learning experience and can minimize confusion on students' parts regarding expectations.

Finally, students' level of preparation to engage in a learning experience should be assessed during the orientation. As was pointed out earlier, a student may possess many of the competencies to be taught in a lesson or may not possess the prerequisite skills for engaging in a learning episode. It is important for the instructor to know the level of entering knowledge and behavior of students so that action can be taken to accelerate or remediate students as appropriate.

Presentation

The presentation phase should start with directions and administrative procedures. These "housekeeping" activities are important during this phase and in each of the successive phases described in this chapter. Students should understand when and where questions should be asked, the teacher's expectations regarding participation during instruction, and other administrative details.

This phase is predominantely expository in nature, i.e., the student is exposed to the skills to be learned. Although the goal of instruction may be the acquisition of a psychomotor skill, there will also be that verbalizable knowledge and those intellectual skills that are prerequisite to the acquisition of the psychomotor skill. Verbalizable knowledge is used here to mean those facts or propositions which a student must be able to recall, e.g., definitions of technical terminology or the names of tools. An intellectual skill is used here for internal cognitive capabilities requiring more than simple rote memory or recall, e.g., calculating the reduction in diameter necessary to bring a piece of bar stock to a pre-specified diameter.

As has been discussed earlier, a hierarchy of skills should delineate all those capabilities necessary to perform a terminal psychomotor skill. As a result, a hierarchy will possess both psychomotor skills and intellectual skills. The hierarchy will not necessarily articulate the verbalizable knowledge necessary for learning a skill. While it can be argued that verbalizable knowledge is not a prerequisite to performing a skill, such knowledge is essential in order for students to follow instructions during learning, and take directions and communicate with peers regarding a skill. Machinists would be hard pressed, for example, to follow a repair manual if they did not know the appropriate names of essential tools or procedures.

For the acquisition of verbalizable knowledge, students should be presented the critical information to be learned without extraneous detail. The students should, however, be exposed to the context for the facts, i.e., how the facts relate to the psychomotor skill that is being learned. For example, students learning terminology related to the components of a lathe should also be informed about how this terminology relates to the psychomotor skill or skills that are to be learned while using the lathe.

For skill learning, students should be presented applications of the processes and procedures to be learned. Gentile (1972) has suggested that for initial skill acquisition the goal of the teacher is to specify the problem or the nature of the *outcome* that is expected of the student. She suggests, however, that an overemphasis upon the verbal description of the movement could result in the student considering the goal of instruction to be replicating the motions of the teacher rather than producing the end product. She refers to this as a kind of *goal-confusion*. There are, for example, many different ways to hold a hammer or baseball bat and to direct the object at its target. The goal for a student is to strike the target in a fashion that results in the desired outcome, not merely to hold the object the way the teacher describes or demonstrates.

DeCaro, Braverman and Barron (1977) have utilized a two phase demonstration technique to achieve this end. These authors first provided students with an explicit outcome for a learning exercise: center-drilling a piece of bar stock to a specified diameter on a lathe. Once the objective was understood, they utilized a videotape of an expert demonstrating the skill in modified real time. The demonstration was executed at approximately half the speed with which the expert would normally perform the task. During the demonstration, the major components of the skill were identified through the use of superimposed captions on the bottom of the screen. No other verbal descriptors were used during this initial demonstration. Such a demonstration provided the learner with an overview of the entire skill to be learned. It also provided the student the opportunity to mobilize any previous motor plans they may have stored in cognitive structure and begin to formulate a strategy for executing the new skill.

The modified real-time demonstration of the skill was immediately followed on the videotape by a step-by-step demonstration of the skill. During the step-by-step demonstration every component of the skill was demonstrated and a superimposed caption was placed on the screen that verbally described what the demonstrator was doing.

The captions and the narrative on the videotape emphasized the desired outcomes for each component and not the instructor's movements (See Figure 7-2).

The videotape was produced in modified real time and step-by-step format because of the complex nature of the skill being taught. There is, however, evidence that compression of a demonstration up to 33-1/3% does not adversely affect a student's ability to perform a simple psychomotor task (Masterson, 1976). This author suggests that compression be used conservatively and attempted only if the skill to be learned is judged by the instructor to be simple for the student.

The videotaping was done from a subjective camera angle so as to replicate as closely as possible what the learners would see as they performed the skill. Roshal (1962) found that such a condition (0° camera angle) was clearly superior to an observer camera angle (180° camera angle). He concluded that film would be "... more effective in the teaching of perceptual-motor acts as they approach an accurate representation, continuously, of all the changes involved in the act... this film should show true movement and not simply static stages of the act" (p. 174).

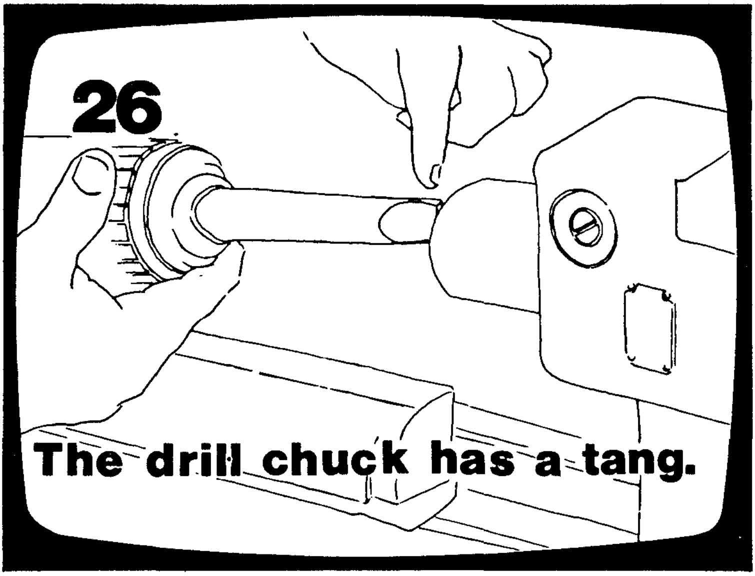


Figure 7-2. An example frame from the videotape.

There are common errors which are often made by students during initial trials in learning a psychomotor task. In addition, there are common points of confusion that will arise during the learning of the task. For this reason, it is suggested that instructors be prepared to explain common errors or points of confusion during the presentation stage (Huttenlocher, 1962). Merrill (1971) suggests that when there is a concern that the student will not attend to the appropriate cue, it is critical that the cue be made distinctive. DeCaro et al. (1977) did this by providing the student with cues during the presentation, e.g., *the bar stock should look like this (example presented) when it is in the lathe chuck.*

The presentation stage should include a variety of examples in order to facilitate transfer to new situations (Tenneyson, Wolley & Merrill, 1972; Tenneyson, Steve & Boutwell, 1976). Examples should range from easy to hard and should be presented in an order of increasing difficulty. The presentation should include the same type of examples as occur in the practice, review and evaluation stage. That is, after having demonstrated the skill of centerdrilling on a lathe the instructor could demonstrate the same process with a softer metal and/or a piece of square stock rather than round stock.

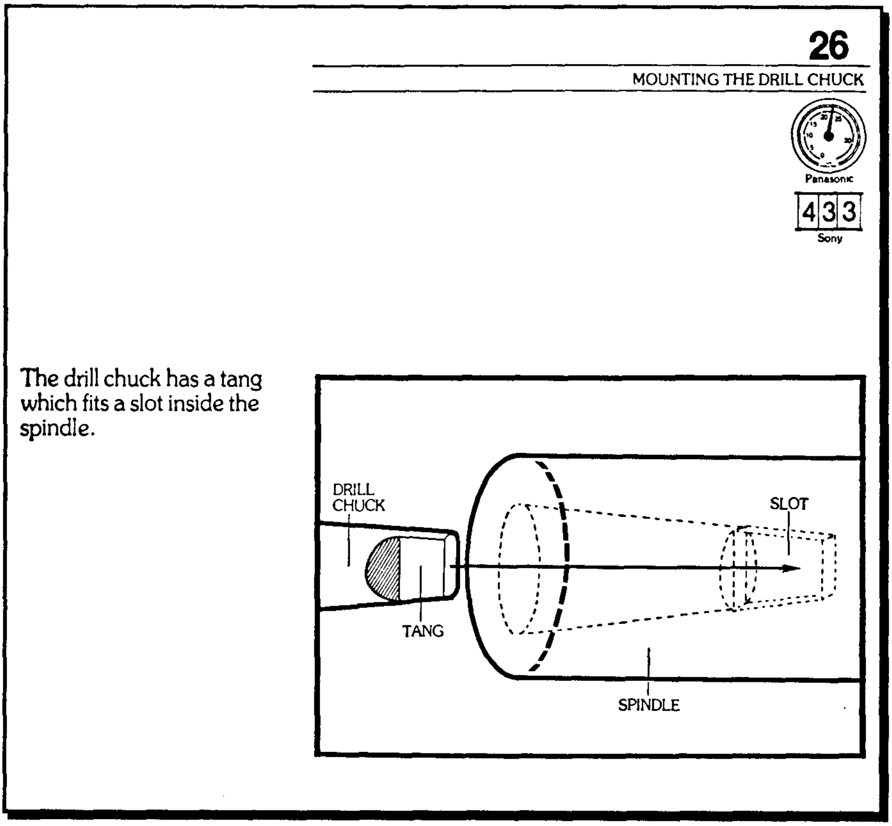
Practice — Assisted and Unassisted

Directions and administrative procedures should be reinforced at the start of the practice phase. The statement of such directions and procedures plays a very important role in practice since it is usually during practice that there is the greatest probability for physical harm to a student attempting to develop a psychomotor skill. It is during this stage that there is the greatest likelihood of accidents, e.g., a student striking another learner with a bat, a student being cut on a piece of machinery, and the like.

For learning verbalizable knowledge, the student should complete memory drills and exercises to firmly establish mastery (Klausmeier & Feldman, 1975). The learning of facts and propositions can, however, be a very tedious activity and teachers should make efforts to enliven the learning with activities other than pure drill and practice. Keesan (1980) has, for example, utilized crossword puzzles and computer generated word-search puzzles as practice exercises in the teaching of technical terminology.

Memory aids, rules of thumb, cues and prompts should be available to students during initial practice (Bower, Clark, Lesgold & Winzez, 1969). As practice progresses, however, guidance should be faded, until the learner receives feedback only after a practice exercise is completed (Anderson & Faust, 1967; Kulhavy, 1977). Merrill (1971) has suggested that it is not desirable to present the student with a full array of prompts and then completely withdraw them on the subsequent trial. He suggests that a more useful and desirable procedure involves the gradual withdrawal of prompts over several trials. Students learning a psychomotor skill will make successive approximations to the desired criterion of proficiency and speed of performance with additional trials of the skill. For this reason, Merrill suggests that the student should be provided a response comparison in the form of time expectations and other acceptable tolerances for the product of each trial. An example of how these principles may be operationalized follows.

DeCaro et al. (1977) developed a workbook for which each page corresponded to a step in the process of centerdrilling on a lathe (see Figure 7-3).



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MOUNTING THE DRILL CHUCK

The drill chuck has a tang which fits a slot inside the spindle.

Figure 7-3. An example page from the instructional materials.

After viewing the demonstration described earlier, the student carried the workbook into the lab and proceeded to follow the steps illustrated in the workbook. The illustrations served as response comparisons and were intended to provide the learner with knowledge of results and an opportunity for self-evaluation.

The students were not required to do one page and then proceed to the next but were provided the flexibility of reading two or three pages (steps) prior to performing the steps at the lathe. This allowed the students to group together related skills on the basis of their capabilities. There were, however, prespecified steps at which the instructor either observed or inspected the end product of the step. The steps were those points at which mistakes would result in compounded errors at later steps or an inability to proceed. At these points the learner was provided with external personal feedback and knowledge of results by the instructor. In addition, the learner could ask the instructor for help at any time difficulties were encountered.

Upon completion of all the steps in the workbook, the product of the entire exercise was evaluated by the instructor, and the learner was provided with summative feedback. The learner was then given a step-by-step outline sheet that listed the steps in the process, deprived of further use of the booklet (prompts were being faded), and required to perform the skill a second time. Upon completion of this exercise, the learner was deprived of further instructional support and required to perform the psychomotor skill without prompts in a new situation. The learner, therefore, practiced the complex psychomotor skill at least twice prior to performing the skill in the absence of feedback.

There are a variety of ways of conceptualizing feedback with the above being one operational example. Some instructional developers and teachers have provided learners with simple one-word feedback statements — "correct" or "incorrect." Others have provided learners with complex verbal explications regarding the nature of their response — "you have done that incorrectly because you . . ." Kulhavy (1975) has proposed a system of organizing and classifying feedback. He suggested that feedback is a unitary variable ranging along a continuum of form. The simplest "correct-incorrect" is at one end of the continiuum and "new instruction" is at the other end of the continuum. In effect, feedback ranges from simple knowledge of correctness to a presentation of substantial remedial information and corrective instruction. Feedback can be provided by way of a videotape (Baker, 1973), an instructor, or printed materials. It is appropriate for the feedback to be of a complete nature for early trials in skill development (at the "new instruction" end of the continuum) and proceed toward the opposite end of the continuum in later trials. For the final trial, students should exhibit skills in the absence of prompts and feedback.

Review

The student should know the procedures and directions to be followed in the review. Many students do not possess adequate review skills and it is therefore very helpful to provide a series of review strategies. Review can be facilitated by teacher-generated and student-generated review exercises. In addition, a teacher-generated lesson summary can also be helpful. Such a summary could be supplied for initial lessons, and students could be encouraged or required to generate their own for subsequent lessons. During the review phase, the student should have free access to all previous instructional materials.

A review might not occur until after several presentation and practice exercises. This would result in a substantial time delay between initial learning and evaluation. A student might, for example, receive several presentation and practice lessons prior to being given a final evaluation project which requires application of some psychomotor skills. In such cases, it is especially important to provide for a review phase (Anderson & Myrow, 1971; Anderson & Carter, 1972; Gagné, 1977; Gagné & Briggs, 1974).

Evaluation

At some point in a learning experience, it is necessary to determine if students have achieved mastery of the skills to be learned, i.e., an evaluation phase. The evaluation phase could be used for two purposes: for providing formative information to students regarding areas in which they need improvement, or for providing information for making summative judgments regarding student performance. It is, therefore, very important for the directions to include the purposes for the evaluation. In addition, the directions should include the procedures to be used for the evaluation: open or closed book evaluation, time limits on the evaluation, and the like.

As stated previously, the goals and objectives of the learning experience should be set out in the orientation. The learning activities in the presentation, practice, review and evaluation should reflect those goals and objectives. The evaluation should contain no surprises for the students and should address the learners' mastery of the objectives of the learning exercise.

For verbalizable knowledge, test items should evaluate what students have been presented, practiced and have reviewed (Gagné & Briggs, 1974). For skills, the evaluation items should be like those encountered in presentation, practice and review (Popham, 1974). A teacher should, however, never use the same examples in the evaluation as were used in presentation, practice and review. Many learners are quite adept at memorizing examples and reproducing them at a later time. Students must be required to apply procedures and processes to problems that are similar to but not the same as previous examples (*nota bene:* a student's ability to state processes and procedures does not necessarily indicate the ability to perform them).

When constructing the evaluation, the teacher should always refer back to the prespecified objectives of the learning exercise. If an objective of the learning episode was transfer to new situations, the evaluation exercises should include transfer type evaluation items. If however an objective was not transfer, the evaluation exercises should not include transfer type exercises.

Table 7-2 provides the reader with an abbreviated summary of the recommendations contained in this section. The five phases presented in this chapter are similar in nature to the steps for instruction in psychomotor skills detailed by DeCecco and Crawford (1974). They suggest that an instructor take the following steps in teaching a psychomotor skill:

1. Analyze the skill.
2. Assess the entering skill level of the student.
3. Arrange for training the student in the component unit of the skill or ability.
4. Describe and demonstrate the skill for the student.
5. Provide for contiguity of stimulus-response, provide opportunity for the student to practice and provide the student with feedback.

SUMMARY AND CONCLUSIONS

There are certain recommendations, that have been put forward in this chapter, which can lead to a more scientific and systematic approach to psychomotor instruction. The author of the chapter recommends that an instructor should consider three issues prior to designing instruction for psychomotor skills. First, he recommends that the skill or skills to be learned should be analyzed and sequenced for instruction. Second, he suggests that the instructor should determine whether demonstration, discovery or a combined instructional methodology is appropriate for the skills to be learned. Finally, he suggests that efforts should be made to consider the variety of learning environments that can foster motivation to learn a skill or skills. These three issues are not comprehensive but are critical considerations that are often overlooked by those of us engaged in teaching psychomotor skills. In addition to these three issues, this chapter presents five instructional design considerations for the reader to ponder.

TABLE 7-2
FIVE PHASES OF EFFECTIVE INSTRUCTION

Orientation	**Presentation**	**Practice**		**Review**	**Evaluation**
		Assisted	**Unassisted**		
Directions Provided: Policies and Procedures Given	Directions provided: Procedures	Directions Provided: Procedures	Directions Provided: Procedures	Directions Provided: Procedures	Directions Provided: Procedures
Introduction: Detail the goals and purpose in curriculum, provide overview and benefits of learning	—	—	—	—	—
—	Assistance: Point out common areas of confusion	Assistance: Memory aids, rule of thumb, prompts, cues provided but faded over time	Assistance: None provided, decreasing time allowed for practice	Assistance: Provided at learner's request, learner access to all previous materials	Assistance: Can be an open or closed-book assessment
—	For Knowledge: Provide information to be memorized	For Knowledge: Provide information to be memorized	For Knowledge: Provide information to be memorized	—	For Knowledge: Assess information memorized
—	For Skills: Provide rules, procedures, and definitions, articulate common points of confusion	For Skills: Provide rules and procedures	For Skills: Provide rules and procedures	—	For Skills: Assess application of rules and procedures
—	Examples: Variety, easy to hard, similar to evaluation examples	Examples/Exercises: Variety, easy to hard, similar to evaluation examples	Examples/Exercises: Variety, easy to hard, similar to evaluation examples	—	Examples: Similar but different from practice exercises
—	Learner Response: Optional but recommended	Learner Response: Required	Learner Response: Required	Learner Response: Optional but recommended	Learner Response: Required
—	—	Feedback: *During* trials	Feedback: *After* trials	Feedback: Provided at learner's request	Feedback: After completion of the test
Expectations: Explicit objectives provided	—	—	—	—	—

NOTE. From "Teaching young deaf people: An instructional strategy" by J.J. DeCaro and R.S. Blake, 1981, American Annals of the Deaf, *126* (7), p. 854. Copyright 1981 by Conference of Educational Administrators Serving the Deaf, Inc., and Convention of American Instructors of the Deaf, Inc. Adapted by permission.

The author delineates five phases that should be incorporated into an institutional strategy to teach psychomotor skills: an orientation phase, a presentation phase, a practice phase, a review phase, and an evaluation phase. He suggests that these five phases of instruction transcend content, mode of delivery and type of skill to be learned. Table 7-2 summarizes his recommendation and can be used as a guide by the teacher developing instruction for psychomotor skills.

This author has attempted to present a series of recommendations that can be utilized by teachers in the design, development and implementation of psychomotor instruction. It should, however, be clear to the reader of this chapter that there is considerable room for judgment as instruction is prepared.

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Chapter 8

Factors Influencing Perceptual and Psychomotor Performance: Effects of Environmental Stressors

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Whether the movements of interest are those associated with operating a drill press, playing a piano, or running for a touchdown, they all have similar functional characteristics. Certain perceptual, cognitive, and motor processes are required to integrate the electrical, chemical, and mechanical components of a voluntary response. Any number of factors can disrupt these fundamental processes and thereby impair performance or jeopardize personal health and safety. Control of these factors can only come from expanding our knowledge of the effects of such factors (stressors) on motor skill acquisition and performance. This chapter identifies and discusses only a few of the factors affecting perceptual and psychomotor performance — those which might be labelled as environmental stressors.

It may be helpful to begin discussing environmental stressors with brief definitions of several forms of stress. A stress reaction, the nonspecific response of the body to a demand, may manifest itself in a number of different ways, including reduced physical work output, impaired cognitive performance, compensatory physiological reactions, and altered emotional reactions (Selye, 1973). The focus of this review is primarily the cognitive and emotional aspects of stress reactions, which some feel are most important (Cohen, Glass, & Phillips, 1977; Kantowitz & Sorkin, 1983).

Psychological stress usually stems from a perceived imbalance between an individual's response capabilities (influenced by innate capacities, training, and physiological states) and the inherent demands of the tasks to be performed, impinging environmental factors, and social settings which either over- or under-stimulate the individual (also see Broadbent, 1971; Cox, 1978; Hockey, 1979; Kantowitz & Sorkin, 1983; McGrath, 1970; Sanders, 1983; Welford, 1973). This condition occurs only when there is motivation to maintain optimal performance levels and the consequences of such imbalances are regarded as important (McGrath, 1970; Sells, 1970).

In contrast, an *environmental stressor* may be any condition or aspect of a physical environment which in some way impairs human sensory, cognitive, or motor functions or somehow poses a threat to personal health and safety (Vercruyssen, 1984; Vercruyssen & Noble, 1984). Alone or in conjunction with machine systems, an individual may be called upon to perform a wide range of tasks in a multitude of environmental conditions, many of which are quite hostile in one way or another. Environmental stressors are thought to impair performance and their influence is often measured by the degree of degradation attributed to direct exposure to the stressor conditions.

Our aim in preparing this chapter is to provide an overview of literature on key environmental stressors. We begin with a brief general discussion of methodological considerations. This is followed by a review of studies of the effects of noise, temperature, drugs, gases, and adverse lighting (alone or in combination) upon performance. Next

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are our conclusions regarding environmental stressors and, finally, resource materials for the interested reader.

It should be understood that in the process of distilling the results of a good many empirical investigations of varying quality, we necessarily have oversimplified some of the original findings. We therefore encourage the reader to consult the references listed in the section on resource material and/or the primary sources whenever addressing a specific problem.

STRESSOR RESEARCH

The bulk of the research on stressors has been done in the context of human factors, engineering psychology, ergonomics, and human performance. These are related interdisciplinary fields that have sprung from the parent fields of psychology, engineering, physical education, physiology, and medicine. Those scientists working on stressor research bring the biases of their parent disciplines with them, of course. All, however, share a concern for understanding and controlling factors influencing human behavior in order to arrange people and design machines with consideration going to the abilities and limitations of human operators. Some aspects of this are understood reasonably well, but unfortunately much of the research on stressors has been unsystematic and poorly controlled, leading to equivocal results and uninterpretable findings. Consequently, we are not yet able to provide models and theories which enable us to explain effects of stressors with considerable confidence and to predict well what will occur in new situations. Landy and Trumbo (1980, pp. 571-572) describe this point as follows:

> Different stressors affect performance on different tasks in different, and sometimes contrasting ways. Furthermore, some stressors may affect one task or one measure of performance but not another. That is, while one stressor may reduce performance rate but not affect error rate, another may increase errors without affecting the rate of performance. Unless some attempt is made to understand such complex and seemingly contradictory results in terms of underlying functions or mechanisms, it is difficult to see how we can arrive at those broader generalizations from which predictions can be made.

Despite this awkward state and slow theoretical development, there have been enough well-controlled, systematic investigations to permit some understanding of how stressors affect perceptual and psychomotor performance (see Sanders, 1981, 1983, and Selye, 1979).

Detecting performance degradation is not an easy undertaking. It is only after having done some research in this area that one truly comes to appreciate

> . . . the diversity, indeed enormity of this problem of predicting performance change as a function of environmental stress. There are so many extraneous factors which may combine in no simple way to decide the ultimate effect of a stress(or) upon performance. In the short term, the very complexity of the picture that arises before us may argue the case for *ad hoc* experiments, designed to provide a specific answer for a specific question — how much will performance be debased by this particular combination of stress and task conditions (Wilkinson, pp. 270-271, 1969).

It is extremely difficult to postulate how much deviation from optimal conditions a person can tolerate before impairment in performance occurs. Such factors as previous experience with the task and stressor may further confuse predictions. Well-learned tasks, for instance, are usually more resistant to the adverse influence of stressors than more poorly learned tasks. And to further complicate the issue with repeated exposures, we are able to adapt (acclimatize) or even become desensitized to many aspects of hostile environments.

The Hawthorne studies (see Roethlisberger & Dickerson, 1939) may be used to illustrate certain experimental control problems. At the time that these studies were initiated, it was generally assumed that if monetary incentives were held constant, differences in the productivity of workers would be a result entirely of differences in the physical environment, e.g., temperature, illumination, and physical fatigue. In keeping with this, the original concern of the Hawthorne experiments was to determine the effects of illumination on worker productivity. After considerable effort, no relationship was uncovered and it became obvious that investigations of the effects of the physical environment are certainly not as simple as one might initially expect. Instead, the Hawthorne studies demonstrate that job performance may be more affected by a worker's attitude toward the illumination, the investigators, the worker's supervisors, or the worker's responsibilities, than by conditions of the physical environment. Controlling such factors is a major task for investigators of environmental stressors as well.

Although this chapter focuses on the effects of individual stressors, in reality we encounter a variety of stressors simultaneously. Moreover, it is incorrect to assume that the detrimental effects of stressors simply add together since there is considerable evidence to suggest that the effects of stressors interact to affect performance in quite different ways depending on the circumstances of the experiment (Poulton, 1970, 1976; Wilkinson, 1969).

Our selective review of the literature leads us to conclude that the effects of a stressor on performance obtained in a research study will depend upon: (1) aspects of the research methodologies employed, (2) the nature of the task, (3) the characteristics of the stressor, (4) the state of the individual, and (5) the interaction of stressors (also see Vercruyssen, Noble, & Christina, 1984). Following are specific examples of how certain environmental stressors affect human performance.

EXAMPLES OF THE EFFECTS OF STRESSORS

Generally speaking, all environmental stressors influence human performance to some degree. Environmental factors which occur naturally and exert a relatively constant influence on human behavior may be considered natural factors, whereas environmental factors which are created by human intervention may be called artificial factors. Examples of natural physical environmental agents and energies which may become environmental stressors include atmospheric conditions (temperature, humidity, barometric pressure, etc.), sunlight, air composition, and ionization. Examples of artificial physical environmental agents and energies which may become environmental stressors include atmospheric pollution (by human actions), changes in ambient gases (e.g., carbon monoxide, carbon dioxide, ozone), and mechanical factors (noise, vibration, motion, etc.). [Further differentiations are available elsewhere (Folk, 1966; Poulton, 1970; Wilkins, 1982).] At extreme levels, all of these factors may seriously affect performance, but at mild levels there may be only negligible effects.

The next section of this chapter presents some of the many factors known to influence perceptual and psychomotor performance; namely, sound, temperature, drugs, gas, light, and combinations of stressors. Drug ingestion is technically not an environmental stressor, however, it is included here because of its widespread use and significance in learning and performance settings. Consult resources listed at the end of this chapter for more information on preventing performance degradation due to exposure to these factors by designing environments conducive to optimal performance.

Effects of Sound: Noise Stress

Noise has been one of the most thoroughly investigated environmental stressors and it is therefore an appropriate starting point for discussing examples of the effects of stressors on performance. The purpose of this section is to outline some of the effects of noise stress on health and performance. It begins with a brief description of the nature and measurement of sound before discussing noise, annoyance, hearing loss, performance impairment, and the benefits of music.

Description of Sound

Sound can be described according to its frequency, amplitude, loudness, pitch, and timbre. When a sound is emitted from some source, there are increases and decreases in the air pressure. If, for instance, someone strikes a drum with considerable force, the amplitude of these changes in air pressure are large; if the drum is merely tapped, the amplitude of the air pressure change is small. The changes in air pressure affect our auditory receptors, and we hear the sound from the drum. The standard method of describing these sound pressure levels is in units called decibels (dB).*

Our perception of the loudness of sounds is related to (but is not identical to) amplitude as expressed by the decibel scale. For example, leaves rustling in a slight breeze are about 10 dB, ordinary conversation when separated by about a yard is approximately 60 dB, light traffic noise is in the neighborhood of 75 dB, and a rock band can be 110-120 dB. Loudness is related to the mechanical pressure against the ear.

In addition to amplitude, sounds are described physically in terms of frequency, which refers to the number of alternating increases or decreases in air pressure per second. The physical scale is named after a scientist named Hertz, and is abbreviated Hz. This scale simply describes the number of cycles per second the sound wave makes, e.g., 3000 Hz means 3000 cycles per second. There is a relationship between frequency and our perception of the pitch of the sound, i.e., the greater the frequency, the higher the pitch.

Almost all sounds consist of combinations of frequencies ranging from 20 to 20,000 Hz.** Complex sounds can be quantified according to their frequencies and the power at each of those frequencies. It is the particular combination that allows us to distinguish the same note played on a violin from that note being played on the piano, or distinguish two soprano voices. These differences, as perceived by the individual are referred to as the *timbre* of the sounds.

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*There are three commonly used decibel scales, A, B, and C. These are similar, but for the purpose of this chapter we shall be referring to the "A" scale, i.e., dB(A), unless otherwise specified.

**This range applies only to healthy young individuals. Most young adults cannot hear beyond 16,000 Hz. Healthy middle-aged subjects are likely to have difficulty hearing above 12,000 Hz. Speech occurs at 250-4,000 Hz.

Among the many excellent books, Bouma (1979), Deatherage (1972), Thurlow (1971), and Vos and Plomp (1979) may be used as initial resources for information on hearing, the presentation of auditory signals, and perception. On a more theoretical level, Broadbent (1978) provides a commentary on the current state of noise research, while Herbert (1976) and Hockey (1978) discuss noise research with respect to human work efficiency.

Noise and Annoyance

Sounds are usually considered noise when they are unwanted, uncomfortable, distracting, intrusive, annoying, irritating, nonsymbolic in nature, or physically injuring. This is not an adequate definition, however, since sound thought to be noise to one person might be music (i.e., pleasant) to someone else. Thus, to simplify discussion it will be assumed that reactions to noise are consistent across individuals. We are constantly exposed to a wide variety of noises, ranging from barely audible electrical sounds (e.g., fluorescent lights at 0-10 dB or a soft whisper at 20 dB) to power lawn mowers (approximately 90 dB), to jets taking off (130 dB at 200 ft.) and rock bands (around 120 dB), or even to the point where sound becomes physically painful (about 140 dB). We usually adapt and pay little attention to many of these sounds, that is unless they become annoying, at which time performance may suffer.

The degree to which a sound (noise) is judged to be annoying depends on loudness, pitch, predictability, and the degree to which it is under the control of the listener/evaluator (Glass & Singer, 1972b; Herbert, 1976; Kryter, 1970). The greater the listener's control of the sound characteristics and the starting and stopping of the noise, the less annoying it becomes. Moreover, according to Miller (1974), one's degree of annoyance with noise depends in part on one's attitude toward the noise source: (1) whether it is perceived as a worthwhile activity, (2) whether it is perceived as necessary, (3) whether those in authority over the noise are perceived as being sensitive to the welfare of those exposed to it, and (4) whether there is a fear of possible danger. Other considerations appear to be the nature of the listener's activity, the listener's motivation to perform the assigned task, the amount of time spent performing the task, and the degree of habituation to the noise.

Fiedler and Fiedler's (1975) "Port Noise Complaints" examined the noise complaints of residents living near a large airport and found nearly identical complaints for those living in the low-noise area to those found in the high-noise areas. They concluded that neither the intensity, type, nor source of the noise influenced its annoyance potential as much as did the individual's "vulnerability" to the noise and subsequent strategies adopted to cope with the noise.

Hearing Loss

Noise interferes with the perception of sound and performance by inducing hearing loss, masking detection of a wanted sound (task interference), and increasing worker stress, fatigue, or training time. Hearing loss is associated with the noise (pressure) levels, duration of exposure, and the bandwidth within which the energy is concentrated. Temporary hearing losses occur rapidly and peak within approximately seven minutes when exposed to pure tones. Low frequency noises of sufficient loudness can produce the most serious hearing impairments, but high frequency noises usually interfere most with performance and are considered the most annoying. Intermediate frequency noises tend to impair the hearing of speech. While noise may induce temporary neurological, endocrinological, and cardiovascular changes, it doesn't seem to cause permanent damage (Kryter, 1970) in most cases. However, permanent irreversible damage may occur for exposures to moderate noise levels (around 90 dB) for long periods of time or to very loud, brief sounds. Ambient and specific noise sources within the work environment should be frequently monitored and appropriate measures taken to lessen the risks of ear damage and hearing loss. When permanent damage does result, it is often difficult to assess the contribution of noise (National Institute for Occupational Safety and Health [NIOSH], 1972b). Also see Bell (1974) and Kryter (1976, 1980).

Performance Impairment

Among the variables which determine the degree to which noise impairs performance, five are discussed in this section: type of noise, type of task, effects of time-on-task, organismic considerations, and aftereffects.

Type of Noise. Generally, continual loud noise (90 dB or higher) can cause performance degradation, but at lower levels it may improve, impair, or have no effect on performance. Intense intermittent noise (95 dB or higher) will almost certainly impair performance, but noise of lower intensity probably will not have a detrimental effect. Intermittent, unpredictable noises appear to impair performance more than continuous noise. High frequency noise (greater than 1200 Hz) usually interferes with performance (increases in errors) more than relevant low noise (Broadbent, 1957a, 1957b). Irrelevant high frequency sounds and unpredictable noises seem to be distracting (which may lead to impaired performance), but relevant high frequency tones seem to attract attention and cause temporarily improved performance.

Teichner, Arees, and Reilly (1963) made a significant contribution to this field in a series of studies demonstrating a relationship between performance impairment and changes in levels of noise. They felt that the changes in noise were the source of the distraction and that more errors were made when noise was changed (e.g., 81 to 93 dB or 81 to 69 dB) than when noise was constant. They further showed that the degradation was proportional to the amount of change, regardless of whether the level was increased or decreased. Their interpretation of the results introduced the idea that arousal followed sudden level changes and then adaptation (habituation) occurred after a period of time.

Type of Task. The effect noise has on performance appears to depend on the type of task used. A low level of noise may increase the percentage of signals detected in vigilance tasks, but at higher levels, intense noise has a detrimental effect, decreasing signal detection. On the other hand, where signal rate is higher than in vigilance tasks, noise appears to have no effect on the rate of responding in a serial reaction task, but does increase errors (Broadbent, 1970; Poulton, 1970).

It is often thought that noise will have its greatest effects on complex tasks with relatively high rates of incoming signals and those tasks which require attention to a number of stimuli (e.g., displays) simultaneously (see Warner & Heimstra, 1973). For instance, responses made to visual stimuli in discrete trials show no effect of noise (Stevens, 1972). However, when a continuous serial reaction time task (a task in which a response to one stimulus activates the next one in an unpredictable sequence) is employed, loud noise has been shown to increase the number of errors made and the number of unduly long delays in responding (e.g., Broadbent, 1971; Wilkinson, 1963).

Under stressful conditions, an operator's attention is directed toward the more probable sources of information and information from less probable sources is more likely to be missed (Bursill, 1958; Hockey, 1970; Landy & Trumbo, 1980). Apparently, when we are forced to share our attention between an assigned task and noise, an overload condition occurs and performance suffers. Finkelman, Zeitlin, Filippi, and Friend (1977) found that when automobile drivers were required to perform two tasks simultaneously (driving and arithmetic calculations), noise impaired performance, again supporting the notion that humans have difficulty in receiving two different forms of information simultaneously. When driving in heavy traffic, for instance, the volume of car radios is often turned down.

Effects of Time-on-Task. The amount of time-on-task and the degree of task overload may amplify the degrading effects of noise on performance (e.g., Hartley, 1973). According to Broadbent (1954) and Jerison (1957), high intensity noise (95 dB and greater) does not interfere with signal detection in a low input vigilance task until after 60 to 90 minutes. Low-intensity noise seems to improve performance after a considerable time at the task, especially if the noise is intermittent.

Noise does not seem to have a significant effect on the performance rates of high-input tasks (i.e., those with frequent signals), but it does increase errors and it may only take 20 minutes of continual performance before the effect occurs (Wilkinson, 1965; also see Broadbent, 1970). Using Leonard's (1959) serial response task, noise (100 dBA continuous broadband) was found to produce an increase in errors (Broadbent, 1953, 1957a; Wilkinson, 1963) and gaps (Corcoran, 1962), especially toward the end of the 30-minute sessions (also see Hartley & Carpenter, 1974).

Organismic Considerations. The effects of stressors on performance are often dependent upon organismic consideration, such as age, sex, fitness, experience, immediate state, and sensitivity. The interaction of environmental conditions and physical states of the organism can be illustrated by Wilkinson's (1963) work with noise and sleep deprivation. Using a 30-minute serial reaction task, subjects deprived of the previous night's sleep performed with no rate impairment, yet made many more errors than subjects who had had a normal night's sleep.

Weinstein (1978) explored individual sensitivity to noise by monitoring subjects living in college dormitories. Academic performance of the students varied with the level of dissatisfaction with dormitory living, which was primarily a reflection of objection to the noise. Apparently there are considerable individual differences in the way people respond to noise — some adapt to the unpleasantness of the noise while others become even more aware of the noise.

Aftereffects. Certain types of noise exposure have produced performance deterioration beyond the time which one is exposed to the noise (Broadbent, 1954; Frankenhaeuser & Lundberg, 1974; Jerison, 1959; Jones, Chapman & Auburn, 1981; Glass & Singer, 1972a; Percival & Loeb, 1980). Some investigators even suggest that chronic noise stress may cause a lowering of children's reading scores, school achievement, and cognitive skills (Cohen, 1980; Cohen, Evans, Krantz, Stokols, & Kelly, 1981; Cohen, & Weinstein, 1981). Following a series of studies concerning short-term aftereffects, Glass and Singer (1972a) concluded that such effects were the result of cognitive factors. Essentially, they found that aftereffects were not simply from exposure to a noxious stimulant, but could be controlled by the attitude of the individual. Subsequent studies have confirmed the existence of aftereffects with random intermittent noise (Moran & Loeb, 1977; Percival & Loeb, 1980; Rotton, Olszewski, Charleton, & Soler, 1978) and continuous noise (Hartley, 1973; Rotton et al., 1978; Sherrod, Hage, Halpern, & Moore, 1977). Based on the work of Glass and Singer (1972b) and Miller and Norman (1979) it seems that one of the most important variables is the individual's perception of the noisy setting. Another important concern is the amount of control the subject perceives having over the stressor (Graeven, 1975). Furthermore, an attentional interpretation of aftereffects has been provided by Cohen and Spacapan (1978).

Benefits of Music

Additional sound and variations in sound patterns tend to have arousal value and may be beneficial in many situations. This is particularly so for dull, monotonous, uneventful tasks where some sounds in the environment help people remain alert (Eschenbrenner, 1971; Poulton, 1970; Warner, 1969). Probably a sound level of up to 50 dB is of value in such situations. For example, music has sometimes been found to be beneficial in maintaining alertness, reducing errors, and improving morale, which may result in improved performance. Some human factors engineers believe that music has salutary effects on attitudes, improves morale and increases productivity. Despite equivocal findings for objective measures, questionnaires often indicate that workers are favorably disposed toward music and, perhaps as important, that they believe that it increases their production. Music may benefit vigilance performance more than simple noise (Lucaccini, 1969) and it is especially effective in maintaining performance on routine tasks when scheduled for brief periods and timed to correspond with expected lulls in performance (Fox & Embrey, 1972). Industrial music appears to aid performance of simple, repetitive types of tasks, but there is insufficient evidence supporting its benefits on more complex tasks (Fox, 1971). A possible explanation for this finding is that workers, being highly skilled and experienced, have developed stable habits of production and music effects may not be sufficiently strong to break these well-established habit patterns (Kerr, 1945; Smith, 1947).

Conclusions

Jones (1983, pp. 86-88) concludes his discussion of noise as a stressor by making some recommendations. The following comments are extracted from his recommendations:

1. For an 8-hour working day the overall level of noise should be less than 85 dBA.
2. If noise is concentrated in a narrow bandwidth, to diminish the effects of masking, the signals should be at frequencies remote from the noise frequencies. Furthermore, voices, signals, etc. can be heard more clearly if fundamental frequencies are at lower frequencies than the noise.

3. Speech will be satisfactorily received at levels of noise below 80 dBA, but with sustained discourse a maximum level of 70 dBA will help prevent fatigue on the part of the speaker.
4. Practical means for reducing the effects of masking on inner speech include: (a) amplifying speech, (b) excluding noise by the use of networks of headphones and noise-cancelling microphones, and (c) restricting the range of vocabulary to an agreed or well-known set of words.
5. Intermittent noise produces both local and general effects, especially when the noise is unpredictable.
6. Infrequent bursts of noise may have localized effects, the impairment in performance being a function of the noise level.
7. Adverse effects of continuous noise are particularly noticeable in complex multi-component tasks, attention being diverted away from elements of low priority.
8. When compared to continuous noise, variable noise may aid alertness at the end of a long vigil. It should be noted, however, that this will not always occur.
9. Judgments become more extreme in noise: more confidence is expressed about the adequacy of a decision even though, on the basis of sensory evidence, it might be unwarranted.
10. Tasks containing a heavy memory component are susceptible to disruption at relatively low levels of noise.
11. Evidence of the effects of noise on mental and physical health is equivocal.
12. Social aspects of response to noise include a reduction in helping behavior, a more extreme or negative attitude to others, and in some cases noise may potentiate overt aggressive behavior.

Effects of Temperature

The atmospheric conditions which surround us (e.g., temperature, humidity, barometric pressure, ionization) are possibly the most common environmental stressors. Humans can readily adapt to moderate fluctuations in ambient atmospheric conditions, but not to extreme changes; therefore, extreme temperatures may impair performance of certain tasks. Both heat stress and cold stress will be discussed in this section relative to their effects on performance. Hancock (1984a) has carefully reviewed the effects of heat and cold stress on performance and should be consulted by anyone embarking on research in these areas.

Heat Stress

The body normally generates heat as a metabolic byproduct. Excessive body heat is given off by sweating (evaporation), respiration, conduction, and convection to maintain a constant core temperature of 37 degrees (deg) Centigrade (C). An increase of only 2 deg C will impair physiological efficiency (Kantowitz & Sorkin, 1983). Heat exchange with the environment depends on physical activity, dry-bulb temperature, relative humidity, air velocity, radiant temperature, and insulating clothing.

Thermal Comfort. Effective temperature is a scale of perceived thermal comfort based on dry bulb temperature, relative humidity, and air movement, as defined by the American Society of Heating and Ventilation Engineers (see ASHRAE, 1977). Of the three factors used in computing effective temperature, relative humidity is most important in determining relative comfort and efficiency (Pepler, 1958). Gilmer and Deci (1977) describe studies in which temperatures as high as 60 deg C were judged by subjects to be tolerable when humidity was at 10%, but when humidity reached 80%, a temperature of 43.3 deg C was described as intolerable. Fanger's (1972) index of thermal comfort was based on the three components of effective temperature plus activity level and thermal resistance of clothing (clo), but Howell and Kennedy (1979) found it to have only limited application in field studies.

Optimal thermal comfort varies with geographical location, age of the subject, ambient temperature, relative humidity, wind velocity, and sunshine, even when testing occur indoors (Aluciems, 1972a, 1972b; Pepler, 1959; Teichner & Wehrkamp, 1954). Even so, some general statements are available. According to studies conducted by the American Society of Heating and Ventilation Engineers (ASHRAE Guide, 1960), nearly everyone feels comfortable when the ambient temperature is between 16 deg and 22 deg C in the winter and 19 deg and 24 deg C in the summer.

Bell (1974) states that most Americans are comfortable at air temperatures between 20 deg and 22 deg C, with relative humidity values between 40% and 60% and air velocities from 0.13 to 0.18 meters/sec. He further suggests suitable air temperature for clerical workers to be from 19.5 deg to 20.1 deg C, general office workers from 18.3 deg C to 19.5 deg C, active workers in light industry from 15.5 deg to 18.3 deg C, and workers in heavier industries from 12.8 deg C to 15.5 deg C. Further information on thermal comfort appears in Herbert (1976).

Performance Impairment. The effects of heat on physiological functioning are quite well documented (e.g., Burse, 1979), however, the effects of heat stress on cognitive and motor performance have not been well described. The behavioral effects of heat stress have a long history of equivocal results (Baron & Bell, 1976; Bell, Provins, & Hiorns, 1964; Griffiths & Boyce, 1971; Provins & Bell, 1970). Interpretation of these findings is further complicated since many of these studies failed to describe adequately essential characteristics of the ambient environment, such as relative humidity, physical activity, air flow, clo factors, radiant heat, etc. From more recent studies, however, one might generally conclude that heat may improve, degrade, or have no effect on performance, depending on the nature of the task, characteristics of the hot conditions, and the state of the organism (Bell, Fisher, & Loomis, 1978). Kantowitz and Sorkin (1983) suggest that performance may be degraded when effective temperature exceeds 30 deg C with exposure exceeding three hours per day. Greer, Hitt, Sitterly, & Slebodnick (1972) suggest that as a "rule of thumb" performance begins to deteriorate at about 75% of the physiological tolerance limit. Through adaptation, habituation, or motivation, however, it is possible to exceed these thresholds for short periods of time without disrupting performance. Just below the extreme thresholds performance may be impaired, unaffected or improved, depending on situational factors.

Type of Task. With respect to paired associate learning, Allen and Fischer (1978) found performance to be optimal at 22 deg C with impairment resulting when the temperature deviated substantially (up or down). Impairment of mental efficiency was found to be a function of variations in relative humidity. When dry bulb temperature and relative humidity were varied, college students showed substantial changes in rote verbal learning and recall, but when dry and wet bulb temperature were varied while holding relative humidity constant, no differences in performance occurred.

The type of task used may give some explanation for the equivocal results. Those tasks involving simple motor reactions and minimal cognitive demands on encoding, translation, response selection, and motor preparation may not be affected by the stressor or may even benefit from the alerting component of stress arousal. However, tests involving tasks which require higher mental processes, considerable attention and memory manipulations may be more susceptible to performance degradation.

A number of different tasks have shown sensitivity to heat stress. Using Leonard's (1959) 5-choice serial response task, increasing ambient temperature caused increases in errors throughout 30-minute sessions (Pepler, 1959). In a series of dual task (tracking plus visual detection of lights at 20 deg, 50 deg, and 80 deg of visual angle) experiments, Bursill (1958) showed that subjects missed a higher proportion of signals at the wider visual angles in the heat than in normal temperature conditions. When the task was made easier the errors diminished, thereby supporting the notion that the heat caused attentional narrowing rather than a change in visual perception.

Tichauer (1962) found cotton pickers to be most productive between wet bulb temperatures of 24 deg and 27 deg C; pickers slowed down when the temperature was less than 17 deg or greater than 32 deg C. Reading speed and comprehension were impaired when temperature rose over 27 deg C. Similar performance deteriorations were found with mine workers (Wyndham, 1969) and students (Pepler, 1972).

Excessive industrial heat in factories (near furnaces or boiler rooms) was discussed by Crockford (1967) and Hill (1967) with suggestions for improving productivity (reducing performance degradation) under these conditions. Methods of alleviating the detrimental effects of heat stress include: increasing ventilation, wearing protective clothing (e.g., cooling equipment), allowing frequent breaks, requiring time to adapt, and providing adequate water and salt.

Systematically controlling body temperature rather than air temperature, humidity, and air flow, Wilkinson, Fox, Goldsmith, Hampton, and Lewis (1964) showed that different levels of raised body temperature influence performance on two tasks in different (even opposite) ways. Performance on a vigilance task (detecting occasional weak tones) was studied when body temperature was maintained at 37.3, 37.9, or 38.5 deg C. The results showed that on the one hand, the number of failures to detect the weak tone decreased with each increase in temperature, but on the other hand, the reaction time was slower at the highest body temperature. Performance on an arithmetic task (performing simple calculations) first improved and then deteriorated with increases in body temperature. Hancock (1983) found that increasing head temperature by 1 deg C facilitated mental addition rate. Like other stressors, body temperature may degrade or enhance performance depending on the degree of deviation from normal and the nature of the task to be performed. (Also see Poulton & Kerslake, 1965, for improved performance in hot rooms.)

Since red-orange colors are perceived as "warm" and blue-green colors as "cool", one might predict that painting rooms with warm colors might result in a lowering of thermostats and the conservation of energy. Unfortunately, however, Greene and Bell (1980) found that while certain colors were reported by subjects to be more pleasant than others, none affected the perception of thermal comfort. Along this same line of thinking, while illuminating the work area with spectral lights, Berry (1961) asked subjects to perform different tasks and to indicate the point at which the ambient temperature became uncomfortably warm. He found no effect of color on perception of ambient temperature.

Wing (1965), using arithmetic and memory tasks, found effective temperatures over 39 deg C to have no effect for brief exposures (six minutes), but significant performance degradation when exposures exceed 43 minutes. Based on his work, the National Institute of Occupational Safety and Health (NIOSH, 1972a, 1975) has established the lower limits of heat-impaired mental performance. However, Hancock (1980) criticizes the NIOSH limit as being too conservative and recommends limits closer to the human physiological tolerance limits. According to Wing (1965), the thresholds for at least some mental tasks for acclimatization or highly practiced individuals would fall between the lower curve and the curve labeled tolerable physiological limit.

Ramsey and Morrisey (1978) have painstakingly developed isodecrement curves (i.e., functions displaying temperature-exposure time trade-offs where performance decrement is constant) based on tracking, reaction time, coordination, and vigilance tasks. (For further information on the stresses of hot environments, see Kerslake, 1972.)

Cooling Systems

When radiation protection clothing is worn, the body's normal cooling mechanisms are not sufficient to handle extreme heat. Thick insulation prevents heat loss through radiation and convection, and evaporation of sweat on the skin surface is reduced. Portable systems designed to cool the body can increase exposure time to hot environments by prolonging the onset of heat stress. For subjects donning a frozen water garment (frozen water packets enclosed in pockets of a shirt), exposure time in a hot ambient environment (55 deg C) increased 242% (7.2 kg frozen water: 178 min) and 163% (6.2 kg frozen water: 126 min) compared to 52 min without a cooling system (Kamon, 1983). Compared to circulating-liquid garments (battery-operated pump circulates cool liquid through network of capillaries into a frozen cannister heat sink), frozen water garments are better cooling systems for use in the ambient conditions investigated in Kamon's study (1983). Herbert (1976) provides further information for protection against the effects of heat.

Cold Stress

Our bodies attempt to maintain a constant core temperature of 37 deg C in cold environments by shivering and shunting blood flow (restricting flow to the extremities). Body core temperature below 35 deg C is generally considered dangerous since regulation of body temperature is jeopardized (ASHRAE, 1977). Temporary amnesia occurs at 34 deg C. At core temperatures of about 33 deg C, victims begin losing touch with reality (Bell, 1974), and cardiac irregularities, even unconsciousness, occur between 30 deg and 32 deg C (Kantowitz

& Sorkin, 1983). Life is threatened at 28 deg C (ASHRAE, 1977); death usually occurs when core temperature reaches 25 deg C (Bell, 1974). Since cold air cannot hold large amounts of moisture, humidity is not a very important consideration in cold stress. This discussion is restricted to cold temperatures in calm conditions, i.e., where wind velocity is negligible. When air velocity becomes relevant, a wind chill index is essential for calculating maximum exposure times and clothing requirements.

Protective clothing is worn to insulate the body from cold external environments. The amount of insulation provided is typically expressed in *clo* units. One clo is the necessary insulation to keep a nude sedentary man comfortable at 21 deg C, 50% humidity, in a ventilated room. Roughly, one clo is required to compensate for a .96 deg C drop in body temperature (see Rohles, Konz, & Munson, 1980), for a linear model to predict the amount of clothing required for thermal comfort in a given environment.)

Performance Impairment. The behavioral research literature dealing with cold stress appears relatively consistent. This is probably because the direct effects of cooling on skin temperature and the viscosity of fluids in the extremities (particularly the joints) reduces manual dexterity and skin sensitivity in a systematic and progressive fashion. Prolonged cold (ambient temperatures of 12.8 deg C or less) results in chilled hands and feet which in turn causes decreased strength, touch sensitivity, and ability to make fine manipulations (Fox, 1967), increasing with lower temperatures and longer exposures. The individual becomes more awkward and, in time, experiences lapses in memory, loss of ability to concentrate, and impairment of psychological abilities.

Tactual sensitivity, as measured by the ability to discriminate the space separating two points or parallel straight edges placed on the fingers, is considerably impaired as skin temperature is decreased. This decreased sensitivity may begin with temperatures as high as 30 deg C. Kinesthetic sensitivity, the detection of movement, may show impairment beginning around 20 deg C. As temperature decreases these impairments become increasingly more serious (especially around 6 deg C) and severe limitations appear around – 1 deg C. A serious problem is that people are rarely aware of their decreasing skin temperatures in the extremeties and, consequently, fail to initiate preventative or remedial measures. This is often the cause of frostbite.

Type of Task. Impaired manual dexterity may result when hand-skin temperature falls below 15.6 deg C, but this can be partially avoided by spot heating (Lockhart & Kiess, 1971) and depends on the experimental task employed (Lockhart, Kiess, & Clegg, 1975). Common tasks used in cold studies include screw tightening, Purdue Pegboard (assembling washers and collar on a metal peg), knot tying, block packing, block stringing (stringing small blocks with needle and thread), and Craik screw (putting screws into holes). Since decreased manual dexterity is generally associated with reduced tactual sensitivity, particularly when joint surface temperatures drop below 6 deg C (regardless of body core temperature), it might be expected that motor performance involving cold hands might be impaired due to the physiological responses to cold stress.

Lowered body temperature has been shown to decrease both the accuracy and speed of detecting signals in a vigilance task (Poulton, Hitchings, & Brooke, 1965). Although the performance degradation may diminish over time (Teichner & Kobrick, 1955), it is probably due to motivation and strategy changes rather than physiological adaptation. Tasks showing performance decrements associated with cold exposure include time estimation (Baddeley, 1966; Bell, 1975), vigilance (Kissen, Reifler, & Thaler, 1964; Poulton et al., 1965; Vaughan, 1977), verbal memory (Baddeley, Cuccaro, Egstrom, Weltman, & Willis, 1975; Davis, Baddeley, & Hancock, 1975), arithmetic (Bowen, 1968; Davis et al., 1975), tracking (Payne, 1959), and the solution to syllogisms (Davis et al., 1975). In a recent study by Ellis (1982), one hour of cold exposure (– 12 deg C) caused an increase in errors on a serial response task associated with decreases in mean skin temperatures.

Recent temperature research has greatly advanced our understanding of the effects of stressors on perceptual and psychomotor performance. Thus, there are several articles which merit reading, including work by Beshir and Ramsey (1980), Hancock (1980, 1981a, 1981b, 1982, 1983, 1984a, 1984b), Jokl (1982), Ramsey (1983), and Ramsey and Morrissey (1978).

Effects of Psychotropic Drugs

Psychotropic agents are those which produce psychological effects. Many substances produce distinct changes in the state of the individual; however, quantifying their effects on performance remains a difficult endeavor. These drugs can affect the nervous system directly via facilitation or inhibition of neuronal activity, or indirectly via changes in blood supply or content. Three such drugs are discussed in this section: alcohol, stimulants, and depressants.

Alcohol

Physiological Effects. Alcohol affects central nervous system functions by altering the activity of neurotransmitters. By blocking the release (Carmichael & Israel, 1975) and disrupting the synthesis of acetylcholine (Smyth, Martin, Moss, & Beck, 1967), nerve conductance long central cholinergic pathways is lowered (Wesnes & Warburton, 1983). Because cholinergic activity is decreased, it is more difficult to attend to specific stimuli and this results in a decreased awareness of stressful information (Wesnes & Warburton, 1983). Studies have shown that characteristic alpha frequency is lowered when subjects are given moderate to large doses of alcohol (Docter, Naitoh, & Smith, 1966; Holmberg & Martens, 1955; Kalant, 1975; Knott & Venables, 1979). Dominant alpha frequency is lowered to 0.2-1.0 Hertz (Hz) at blood alcohol concentrations (BACs) of 0.05-0.1%. Alpha frequencies of near 3 Hz are reported at BACs of 0.2%. This decrease in arousal causes impairments in skilled performance, concentration, balance, articulation, and memory (Wesnes & Warburton, 1983).

Research findings vary with respect to the effects of alcohol on physical fitness components. Hebbelinck (1959, 1963), Ikai and Steinhaus (1961), and Williams (1969) found no effect of alcohol on muscular strength or local muscular endurance (Williams, 1969). Other studies, however, report that alcohol ingestion may decrease dynamic muscular strength (Hebbelinck, 1963), isometric grip strength (Nelson, 1959), power (Hebbelinck, 1959), ergographic muscular output (Jellinek, 1954), and work output (Bobo, 1972; Mazess, Picon-Reategui, & Thomas, 1968; Williams, 1972). Asmussen and Boje (1948) showed that small doses had no effect but large doses had a deleterious effect upon bicycle ergometer exercise tasks simulating a 100-m dash or 1500-m run. Alcohol was not found to influence physical performance capacity (Garlind, Goldberg, Graf, Perman, Strandell, & Strom, 1960; Graf & Strom, 1960), exercise time at maximal levels (Blomqvist, Saltin, & Mitchell, 1970) or exercise time to exhaustion (Bond, 1979).

By blocking the release of corticosteroids, which increases activity of the serotonergic pathways important for experiencing anxiety, alcohol should reduce anxiety and stress (Wesnes & Warburton, 1983). Studies have shown that moderate doses of alcohol alleviate stress and anxiety and elicit a feeling of euphoria (Lindman & Mellberg, 1976; Lindman & Taxell, 1976; Williams, 1966). Though alcohol can help a person to cope with a sudden shock, it is not effective for long-term stress because of increased tolerance to the drug with repeated use, and a period of depression follows the immediate euphoria experienced (Wesnes & Warburton, 1983). Another effect of alcohol is the markedly decreased utilization of glucose in the brain (Nielsen, Hawkins, & Veech, 1975). Lowered brain glucose causes mental fatigue after the drug wears off (Wesnes & Warburton, 1983).

Performance Impairment. Despite possible improvements in subjective state following alcohol consumption, psychomotor performance deteriorates. Coopersmith (1964) and Persson, Sjoberg, & Svensson (1980) have shown that while alcohol can increase feelings of self-confidence and give one the feeling of being in control, the available research shows that this drug definitely impairs many psychomotor functions, including motor performance, sensory acuity, memory, and, in general, the rate and quality of information processing. Performance impairments have been documented for reaction time (Carpenter, 1962; Huntley, 1972, 1974; Moskowitz & Burns, 1971; Moskowitz & Roth, 1971; Nelson, 1959; Tharp, Rundell, Lester, & Williams, 1974), hand-eye coordination (Carpenter, 1962; Collins, Schroeder, Gilson, & Guedrey, 1971; Forney, Hughes, & Greatbatch, 1964; Siddell & Pless, 1971), accuracy (Nelson, 1959), balance (Begbie, 1966), and complex coordination (Belgrave et al., 1979; Carpenter, 1962; Haffner et al., 1973; Nelson, 1959; Tang & Rosenstein, 1967).

The subjective effects (Ekman et al., 1963) and objective performance decrements are immediately obvious yet people continue to attempt to operate hazardous equipment (including automobiles) while intoxicated. Alcohol is a known causal factor for a large number of driver fatalities (Goldstein, 1962). Fergenson (1978) found progressive deterioration of both short-term memory (consonant-vowel-consonant) and the ability to assess risks with increases in blood alcohol levels (0.00, 0.04, 0.08%). He thought these findings were particularly important in machine operation situations. This point is especially important for those who are just learning to operate complex machinery, since users operating machines with a low skill level and with alcohol in their system are vulnerable to accidents.

Hartley (1983) administered alcohol to 28 subjects to produce a blood alcohol level of 0.075 mgs/100 ml. Using a strategy analysis technique (MacLeod, Hunt, & Mathews, 1978), alcohol was found to impair verbal strategies but improve spatial ones. Generally speaking, in moderate doses, alcohol behaves as an "arouser" and may improve performance in certain conditions (Hamilton & Copeman, 1970; Moskowitz, 1974; Wilkinson & Colquhoun, 1968). However, in most cases alcohol is "de-arousing" or at least anxiolytic.

Studies on the effects of alcohol on driving have shown that alcohol ingestion impairs reaction time and steering efficiency and lowers vigilance to speedometer readings (Drew, Colquhoun, & Long, 1958; Landauer, Pococke, and Plott, 1974; Loomis & West, 1957). Reaction time increases for both single responses to single stimuli (Taeuber et al., 1979; Taberner, 1980) and multiple responses to multiple stimuli (Indestrom & Cadenius, 1968). Alcohol increases the number of errors in a choice reaction test (Taeuber et al., 1979), impairs pursuit rotor tracking (Siddell & Pless, 1971; Valeriote, Tong, & Durdling, 1979), impairs complex coordination (Haffner et al., 1973), and lowers critical flicker fusion frequency (Enzer, Simonson & Ballard, 1944; Haffner et al., 1973). Reaction time performance is even worse when alcohol is combined with sleep deprivation (Wilkinson & Colquhoun, 1968) or medications (e.g., antihistamines, anti-motion sickness drugs, and barbiturates).

Stimulants and Depressants

Cerebral stimulants diminish the perception of fatigue permitting continued activity beyond normal limitations. While there is overwhelming evidence to suggest that amphetamines extend aerobic endurance and speed recovery from fatigue (Ivy, 1983), overdoses may produce nervousness, judgment, disorientation, and euphoria. Benzedrine is known to elevate mood but it also causes a decreased ability to concentrate and insomnia. Caffeine is also a central nervous system (CNS) stimulant.

Included in the depressants category are barbiturates, tranquilizers, sedatives, and bromides. These drugs inhibit CNS activity to induce sleep. They greatly impair alertness, judgment, mental efficiency, and overall performance. They are especially dangerous when used in combination with alcohol because of the severe depressant effects.

Trumbo and Gaillard (1975) found amphetamines speeded visual reaction time (RT) but had no effect on auditory RT; in contrast, barbiturates slowed RT to a 70 dBA tone but not to a visual stimulus. Using a serial reaction task, Frowein and Sanders (1978) found amphetamines to decrease RT, while barbiturates had the reverse effect, especially in fast-paced conditions (also see Truijens, Trumbo, & Wagenaar, 1976). Frowein concluded his doctoral dissertation, *Selective Drug Effects on Information Processing* (1981, p. 176), by saying that "drug effects may be found on the level of attentional control as well as the level of automatic processing, and that on either of these two levels these effects are likely to be selective rather than general." Based on 10 years of research at the Institute for Perception TNO, The Netherlands, Frowein (1981) decided that of the various stages of information processing associated with choice reaction tasks, amphetamines affect only the motor preparation stages, whereas barbiturates affect stimulus encoding. Frowein's results run contrary to those of Ivy (1983, p. 119) who stated that "on the basis of recent literature it is suggested that amphetamines are incapable of improving the reaction time of alert, motivated, not-fatigued subjects." The authors of this chapter side with Frowein for a number of reasons.

Many *prescription medications* also impair performance but the lack of scientific literature limits discussion. For instance, antibiotics like Streptomyocin may produce undesirable clinical reactions such as loss of balance, dizziness, ringing in the ears, and temporary deafness. Antihistamines may cause decreases in attention span, drowsiness, confusion, mental depression, dizziness, decreased vestibular function, and impaired depth perception. Anti-motion sickness medications, like Dramamine, may cause side effects which include: drowsiness, blurred vision, and dizziness (Tang & Rosenstein, 1967). It is important to consider the side-effects of these drugs when operating machinery since the safety of the operator may be seriously jeopardized, especially when these substances are combined with alcohol, sleep deprivation, or other stressors.

Effects of Toxic Gas Inhalation

Our environment contains many hazardous pollutants, including tobacco smoke, exhaust fumes, toxic vapors and gases, herbicides, insecticides, and ionizing radiation. Four topics are briefly discussed here: carbon monoxide, carbon dioxide, air pollution, and welding gases.

Carbon Monoxide

The most prevalent atmospheric contaminant is carbon monoxide (CO). Generally speaking, performance (e.g., time estimation) may be degraded after 90 minutes of exposure to a small amount of CO (similar to that on a moderately traveled freeway at rush hour). As the concentration of CO increases, even less time is required to produce such decrements. Putz (1979) found breathing CO made it more difficult for subjects to attend to two tasks simultaneously. Conversely, while inhalation of moderate to high concentrations of CO caused blood carboryhemoglobin (COHb) levels of 7.6 or 11.2%, respectively, Ramsey (1973) found no impairment of performance in depth perception, brightness discrimination, or flicker fusion discrimination. He did find, however, a significant decrement in visual RT, but since 5 of the 20 subjects actually improved their RTs, it is hard to draw conclusions from these results (also see McFarland, 1970). O'Donnell, Mikulka, Heinig, and Theodore (1971) found no impairment in time estimation on tracking when volunteers inhaled up to 250 ppm of CO (12.37% COHb) for 3 hours. Davies and Parasuraman (1982) provide further information on this stressor.

Operators in any industrial activity (particularly auto mechanics, heavy equipment operators, etc.) and anyone exposed to even moderate levels of exhaust fumes or cigarette smoke (which contains large amounts of CO) are likely to experience such impaired performance over a period of time. Goldsmith and Landaw (1968) suggest that CO adversely affects basic visual functions and further state that CO levels are often quite high in drivers thought to be responsible for traffic accidents.

Carbon Dioxide

Too much carbon dioxide (CO_2) in the body can impair human performance. Hypercapnia, a condition where higher than normal concentrations of CO_2 are present in the blood, has been shown to impair cognitive and motor performance (Vercruyssen, 1984). Using a serial choice reaction time task (Vercruyssen & Noble, 1984), Vercruyssen (1984) found that breathing 4% CO_2 impaired information processing and that the locus of this effect was in the response selection stage rather than an earlier encoding stage. These results are particularly noteworthy since 4% is a subclinical concentration and the subjects were not able to distinguish it from room air.

Air Pollution

While much is known about the harmful physiological effects of breathing polluted air, relatively little is known about the behavioral effects (Evans & Jacobs, 1981). In a literature review of studies dealing with air pollutants, Breisacher (1971) found exposure to relatively small amounts of some pollutants to adversely affect manual dexterity, attention, and reaction time. (Also see Lewis, Baddeley, Bonham, & Lovett, 1970.)

Ionization. The air we breathe is often changed in many ways that we cannot immediately recognize. Electronic equipment, for example, radically alters the electrical charge of the air particles (ionization) as do various weather conditions. While it is premature to make any conclusions, some researchers believe air ionization affects performance. Negative ionization increased RT by 9% compared to a control of room air in one study (Wofford, 1966), and in another, positive ionization produced the impairment (Halcomb & Kirk, 1965). In another study (Hawkins & Barker, 1978), negative ionization improved performance for mirror drawing, rotary pursuit, visual reaction time, and auditory reaction time, but positive ionization had no effect. The present notion for most doing research in this area is that "people have faster RT and report feeling significantly more energetic under negative air ion conditions than under normal air conditions" (Tom, Freeman Poole, Galla, & Berrier, 1981).

Welding Gases

Fumes released from the welding electrode at high temperatures contain a wide variety of substances which are potentially hazardous to the welder. These toxic substances include asbestos, beryllium, cadmium, carbon dioxide, carbon monoxide, copper, fluorides, lead, manganese, mercury, molybdenum, nickel, ozone, phosgene, phosphine, silica, titanium, vanadium, and zinc (Usiak & Gutcher, 1983). Even when the fumes are at levels which are considered legally and scientifically "safe," exposure to these substances may cause performance decrements. Possible effects of exposure include dulled senses, slowed reaction times, and lessened ability to perform delicate maneuvers

(Lehmann, 1973). It is also possible that various behavioral changes may result from exposure to toxic fumes. There is growing evidence to suggest that nervous tissue, especially in the brain, is much more sensitive to many foreign substances in the blood than has been previously suspected, and that the toxic effects of these substances may be manifested as subtle disturbances of behavior long before any symptoms of poisoning are observable (Spyker, 1975).

Usiak and Gutcher (1983) studied the acute effects of exposure to welding fumes on performance skills of university welding students. Six dependent measures were used: (1) Pursuit rotor test, (2) Visual choice test, (3) Groove steadiness test, (4) Hole steadiness test, (5) Purdue pegboard test, and (6) Light coincidence test. In addition, 190 hair samples taken from the first and last week of the testing period were analyzed for changes in concentrations of 31 different elements. Overall, there were improvements in each performance measure, and no trends were discovered to show that acute exposure to welding fumes causes decrements in psychomotor performance. Practically no metallic contamination was found, however, there may not have been sufficient time for the inhaled fumes to move from the lungs through the circulatory system to the hair (Usiak & Gutcher, 1983). Though this study indicates no performance decrements due to exposure to these toxic substances, the time period may have been insufficient to allow the performance levels to stabilize (Usiak & Gutcher, 1983). Since the students are exposed to the fumes for much shorter times than occupational welders, the possibility remains that occupational workers may suffer losses in coordination and psychomotor performance.

Effects of Illumination

When one is in complete darkness, a very small increase in light results in enormous improvements in vision, but with further increases in light, there are diminishing returns in visual improvement. In fact, as light becomes too intense, vision is impaired. Optimization of indoor artificial lighting has received considerable attention. The Hawthorne experiments (Roethlisberger & Dickinson, 1939), beginning in 1929, were designed to determine the effect of illumination on performance. Although no consistent relationship emerged, interest was sparked in this area. Several studies during this period nurtured interest in the effects of illumination. For example, glare was found to impair speed in inspection and typewriting tasks (Weston, 1949), while dim lighting was found to impair reading speed (Tinker, 1943). Insufficient illumination, glare, reflectance, shadows, flickering, and low brightness contrast appear to adversely affect various aspects of human performance (Bell, 1974; Boyce, 1981).

Description of Light

Photometric units have been developed to incorporate a factor for weighting the differential sensitivity of the human eye to wavelengths of light. Illuminance is the amount of light reaching a surface and is measured in footcandles (fc) or lux (lx). Lumens (lm) refer to the total amount of light given off by a source in all directions. The quality of light projected in a specific direction is measured in candelas. Luminance is a metric measure of the amount of light reflecting off a surface and it is expressed in footlamberts, candelas per square meter or in nits. Reflectance is the ratio of reflected light to received light. Usually the luminance of a surface depends on the illuminance and reflectance. Three sources may be of value in understanding the psychophysics of vision and perception: Vos and Plomp (1979), Bouma (1979), and Kling and Riggs (1971).

The quantity of illumination required in a given situation depends on the nature of the task (particularly the demands for speed and accuracy), the worker's visual characteristics, and the luminance distribution of the immediate surroundings. Age of the worker is of critical importance since age brings with it a decrease in visual acuity (the ability to focus and rapidly accommodate different light levels) and resistance to glare. Blackwell and Blackwell (1971) suggest that contrast be elevated by a factor of 1.86 and 2.51 for individuals aged 50 to 60 and 60 to 70 years, respectively. With respect to the legibility of highway signs at night, older subjects seem to take longer than younger subjects to process displayed information indicating that older persons have less time to act on the information. Another point is that most accidental falls on stairs by older persons occur on the first step of landings since this is where there is the greatest decrease in luminance and the visual system apparently fails to make the rapid adaptation required (Fozard & Popkin, 1978).

Well-designed machinery and work stations can greatly contribute to reducing the amount of illumination required. Apparently, the greater the contrast (i.e., the difference in brightness between the relevant objects and their immediate background), the lower the illumination required.

The majority of industrial operations can be performed at maximal efficiency at illumination intensities of around 10 fc. Most factories fall short of this, however, with the average illumination of around 2.4 fc. Guth and Eastman (1955) point out that although it is idealistic to provide for each individual's illumination requirements in a work space, average lighting conditions will necessarily be insufficient for a certain percentage of the work force. Designers should determine the performance requirements of each activity and provide adequate lighting for EVERYONE using this area (for factors related to poor visibility, see Blackwell, 1959, 1964, 1972). The following illumination levels are recommended by Bailey (1982) for various task conditions:

ILLUMINATION LEVEL (Footcandles)	DIFFERENT TASK CONDITIONS
10	General lighting in the home
20	Hallways for passage
30	Reading printed material
50	Ordinary inspection
70	Writing, studying, or notetaking
100	Critical visual task Mail sorting Reading circuit diagrams
150	Rough layout drafting Bench work Computer operation
200	Detailed drafting General assembly Instrument repair
300	Precise assembly
500	Very difficult inspection
1000	Most difficult inspection

Glare

Two forms of glare, direct and specular, reduce the clarity of vision. It is possible, though, to keep glare at a minimum. VanCott & Kinkade (1972) recommend the following for the reduction of direct glare:

1. Avoid intense sources within 60 degrees of any commonly used line of sight.
2. Use shields, hoods, and visors.
3. Use indirect lighting.
4. Use several lower intensity luminaires instead of one very bright one.

Recommendations for the reduction of specular glare as identified by VanCott & Kinkade (1972) are:

1. Use diffuse light.
2. Use dull, matte surfaces instead of polished or glossy ones.
3. Arrange direct light sources so that the viewing angle to the work surface is not equal to the angle of incidence from the source.

Designing optimal lighting conditions is an involved undertaking. Certainly the IES Lighting Handbook (1981a, 1981b) and Boyce's (1981) Human Factors in Lighting should be consulted.

Effects of Stressors in Combination

We function routinely in environments containing multiple stressors which interact in influencing our performance. However, almost all of the research to date has involved only single environmental stressors. Only a few studies have examined the effects of combined stressors but their results often appear as inconsistent as many of those for single stressors. The nature of the stressor, task, time performing the task, skill level in performing the task, acclimatization to the stressor, the length of exposure to the stressor, and the measures of the task performance — all these interact to determine the nature and magnitude of the stressor effects. In view of this it would be premature to offer generalizations about the effects of stressors in combination.

CONCLUSIONS REGARDING THE EFFECTS OF STRESSORS

Among the factors which most influence whether a statistically reliable deterioration in performance can be associated with a particular stressor, four are noteworthy here:

1) aspects of the *research methodology* employed in the investigation (i.e., sensitivity, reliability, and validity of the performance measures; statistical power of the test; experimental design; and transfer effects);
2) the *nature of the task* (e.g., required attentional demands, duration of the task, task priorities, expected criterion level of proficiency, and instructional set employed);
3) the *characteristics of the stressor* (e.g., demands placed on the system, intensity and duration of exposure);
4) the *state of the performer* (e.g., amount of previous experience with the stressor, acclimatization, adaptation, habituation, skill level in performing the task, level of motivation, and trait characteristics).

RESOURCE MATERIALS

This section consists of a listing of available literature relevant to the study of environmental stressors and their effects on performance. The human factors / ergonomics / engineering psychology resources mentioned in this section are divided into two categories: recent general texts and periodicals.

Recent General Texts

Applied ergonomics handbook. (1977). Surrey, England: IPC Science and Technology Press.

Bailey, R.W. (1982). *Human performance engineering: A guide for system designers*. Englewood Cliffs, NJ: Prentice-Hall.

Clark, T., & Corlett, E.N. (1984). *Manual for ergonomic design*. New York: Taylor & Francis.

Diffrient, N., Tilley, A.R., & Bardagjy, J.C. (1974). *Humanscale Vol. 1/2/3*. New York: Dreyfuss.

Fleishman, E.A. (Ed.). (1982). *Human performance and productivity Vol. 1/2/3*. Hillsdale, NJ: Erlbaum.

Grandjean, E. (1980). *Fitting the task to the man*. New York: International Publications Service. Also available from New York: Taylor & Francis.

Hockey, R. (Ed.). (1983). *Stress and fatigue in human performance*. New York: Wiley.

Huchingson, R.D. (1981). *New horizons for human factors in design*. New York: McGraw-Hill.

Kantowitz, B.H., & Sorkin, R.D. (1983). *Human factors: Understanding people-system relationships*. New York: Wiley.

Kraiss, K.F., & Moraal, J. (1976). *Introduction to human engineering*. Kolin, Germany: Verlag TUV Rheinland BmbH.

Maule, H.G., & Weiner, J.S. (Eds.). (1981). *Design for work and use: Case studies in ergonomic practice*. New York: Taylor & Francis.

McCormick, E.J., & Sanders, M.S. (1982). *Human factors in engineering and design* (5th ed.). New York: McGraw-Hill.

Salvendy, G. (Ed.). (1982). *Handbook of industrial engineering*. New York. Wiley-Interscience.

Salvendy, G., & Smith, M.J. (Eds.). (1981). *Machine pacing and occupational stress*. London: Taylor & Francis.

Singleton, W.T., Easterby, R.S., & Whitfield, D. (Eds.). (1976). *The human operator in complex systems*. New York: Taylor & Francis.

Singleton, W.T., Fox, J.G., & Whitfield, D. (Eds.). (1973). *Measurement of man at work*. New York: Taylor & Francis.

Tichauer, E.R. (1978). *The biomechanical basis of ergonomics*. New York: Wiley and Sons.

VanCott, H.P., & Kinkade, R.G. (Eds.). (1972). *Human engineering guide to equipment design*. New York: McGraw-Hill.

Welford, A.T. (Ed.). (1974). *Man under stress*. New York: John Wiley & Sons.

Wickens, C.D. (1984). *Engineering psychology and human performance*. Columbus, OH: Charles E. Merrill.

Woodson, W.E. (1981). *Human factors design handbook*. New York: McGraw-Hill.

Periodicals

Applied Ergonomics: Human factors in technology and society. (In cooperation with the Ergonomics Society.) Butterworth & Co., Kingprint Ltd., Richmond, Surrey, UK: IPC Science and Technology Press.

Aviation, Space, and Environmental Medicine. Washington, DC: Aerospace Medical Association.

Behavior and Information Technology. New York: Taylor & Francis.

Bell System Technical Journal: Human Factors and Behavioral Science. New York: American Telephone & Telegraph.

Ergonomics Abstracts. (Published in association with the Ergonomics Information Analysis Center.) New York: Taylor & Francis.

Ergonomics: An international journal devoted to the scientific study of human factors in relation to working environments and equipment design. (The official publication of the Ergonomics Society, International Ergonomics Association.) London: Taylor & Francis.

Human Factors. Santa Monica, CA: The Human Factors Society, Inc.

Human Factors Association of Canada Annual Meeting Proceedings. Rexdale, Ontario, Canada: Human Factors Association of Canada.

Journal of Human Ergology. Journal of the Human Ergology Research Association. Tokyo, Japan: University of Tokyo Press.

Journal of Motor Behavior. Washington, DC: HELDREF Publications.

NASA: Aerospace Medicine and Biology — A Continuing Bibliography With Indexes. Washington, DC: National Aeronautics and Space Administration.

Proceedings of the International Ergonomics Association and *Proceedings of the Ergonomics Society's Conferences.* Philadelphia, PA: Taylor & Francis (annual meeting).

Proceedings of the Human Factors Society. Santa Monica, CA: The Human Factors Society, Inc. (annual meeting).

Proceedings of the International Conference on Occupational Ergonomics. Rexdale, Ontario, Canada: Human Factors Association of Canada. (annual meeting).

Proceedings of the International Symposium on Attention and Performance. Hillsdale, NJ: Erlbaum.

PsycScan: Applied Psychology. (Abstracts from a Cluster of Subscriber-Selected Journals.) Arlington, VA: American Psychological Association.

STAR: Scientific and Technical Aerospace Reports — An Abstract Journal. BWI Airport, MD: NASA Scientific and Technical Information Facility.

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REACTION TO CHAPTER 8, "FACTORS INFLUENCING PERCEPTUAL AND PSYCHOMOTOR PERFORMANCE: EFFECTS OF ENVIRONMENTAL STRESSORS"

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Drs. Vercruyssen and Noble offer unique insights to members of the profession. We have planned laboratories and taught many courses in laboratory planning; but how much emphasis was placed on placement of equipment and how much emphasis was placed on the factors described in Chapter 8? We have spent a large amount of time discussing appropriate teaching techniques in methods courses; but how much have we explored the effects of environmental stressors on learning? Chapter 8 served two purposes: first, it alerted us to the many and diverse environmental factors which affect learning; second, it offered a multitude of research opportunities concerning those factors and the field of industrial arts education. The extensive list of resources and references certainly will aid in further considerations.

Following are a *potpourri* of ideas and comments derived from Vercruyssen and Noble's chapter which may be of interest to industrial educators.

Acquiring Psychomotor Skills. Many of the experimental studies cited by Vercruyssen and Noble were concerned with completion of tasks: vigilance tasks, serial reaction tasks, and rotary pursuit; or work skills, such as performance impairment, academic performance, and picking cotton. Some of the cited studies also were concerned with cognitive skills and the affective domain. These latter studies, at first thought, did not appear relevant; however, the acquisition of psychomotor skills involves the perceptual, affective, cognitive, and psychomotor domains as well as creativity (PaDelford, in press).

In acquiring psychomotor skills the learner uses perceptual powers to sense symbols or realia and to select, translate, and internalize cues. Most of the debilitating environmental factors would have an effect on perception, with inadequate lighting and noise being the most obvious. The affective domain involves motivational determinants. Adverse temperature, noise, and odors can affect the willingness of students to attempt cooperation in learning. Psychomotor skill attainment involves the cognitive domain which controls the mental manipulation of the form, pattern, or sequence of the skill to be learned; or the mimicking of the series of events, patterns, or procedures. These mental processes, so crucial to learning the skill, are probably the most easily disrupted link in the skill acquisition process. Surely, an uncomfortable environment, including psychotrophic agents, would disturb the process. The psychomotor domain directly affects the performance of the skill, i.e., the initial, medial, and terminal practice engaged in while learning; and also the automatic action that sustains the skill. All of the environmental factors would affect performance by distracting from the concentration and muscular action needed. Creativity, in the acquisition of psychomotor skills, influences adaptation, i.e., diagnosing, reacting, and problem solving; and innovation, i.e., experimenting, expressing, and symbolizing. Each of these needs the full capabilities of the learner in order for the psychomotor skill to be acquired fully and efficiently. The environmental factors discussed by Vercruyssen and Noble all affect the learner's capability and should be considered in all learning situations.

Laboratory Planning Courses. Laboratory planning, as a topic, is usually part of all teacher preparation programs. Much consideration is given to placement of equipment in either "logical sequence" and/or the "best learning environment." Now we can add a new dimension; the enhancement of learning by controlling undesirable noise, air pollution, inadequate lighting, and deviant temperature and humidity. We might look to our college and university laboratories as examples.

Newer Technologies. As industrial arts education moves towards including the newer technologies, i.e., computers, robots, lasers, communications, etc., we must assess how these technologies affect working conditions. As an example, should we include clean rooms which have a tightly controlled environment? It is within our sphere of influence to have students learn about clean rooms and even construct a full-scale model which could be utilized in teaching/learning. It is quite obvious that working environments are becoming less contaminated and more pleasant.

Industrial Arts Laboratories. Students may spend only one or two hours in the laboratory each day, but the instructor could spend six or seven hours there each day so some consideration might be given to the environment within the laboratory.

Noise reduction is attainable by placement of equipment, sound deadening baffles, and ear coverings. Noisy pieces of equipment can be placed farther apart so that a buildup of the sound level is prevented. Baffles which absorb the sound waves might be installed between noise-producing equipment and the students. Baffles may also be placed along walls to prevent echos and reverberation. Ear covering (ear muffs), in some noisy environments, may be as important as safety glasses are in other situations.

Improvement in lighting can be attained with compact source iodide (CSI) lamps, tungsten-halogen, or high pressure sodium lamps supplementing fluorescent lamps. Glare and shadows can be reduced or eliminated by correct placement of the light source. Glare can also be reduced by applying a matte finish on the surfaces that reflect light toward the student. Ten footcandles of illumination should be considered a minimum in all laboratories.

Temperature and humidity are often adjustable only through a building's system. However, many laboratories have high ceilings and could benefit from ceiling fans. Also, humidifiers and dehumidifiers could be utilized to adjust the air for comfort. In areas with high temperatures, such as welding, forging, and heat treating, air conditioners or evaporation coolers should be used to keep the temperature within comfortable limits.

Air pollutants which can become a problem, such as carbon monoxide and welding fumes, are often vented out of the building. But, in too many laboratories the exhaust systems are not totally effective or used 100 percent of the time. Frequently, rooms used for finishing materials are not well ventilated and equipment used in woodworking is not connected to a dust removal system.

Consideration must be given to the comfort of students if we wish to maximize the learning experience. We must all be concerned with the elimination of health hazards. It is not unreasonable to have students aware of the hazards of excessive noise, poor illumination, and air pollutants and the school's efforts to alleviate them.

Sensitivity of Students. Vercruyssen and Noble's work brought forth an interesting phenomenon concerning sensitizing and desensitizing teen-age students. We have all experienced youth listening to Rock and Roll music at 120 dB, or higher it seems, while purporting to be studying. Even college dormitories vibrate with excessive sound. Will there be permanent hearing loss? Can the student learn to her/his full capabilities while rocking and rolling? Or, can students acclimatize themselves so that the noise level does not affect the learning process? This author, in a very un-scientific survey, found students declaring that the music enhances learning! But Vercruyssen and Noble note that noise might elicite a reduction of helping behavior, a more extreme or negative attitude toward others, and even overt aggressive behavior. This phenomenon leaves many questions unanswered without empirical study.

Resources and References. Great appreciation is to be extended to Vercruyssen and Noble for the extensive and thorough list of resource materials and references. Anyone wishing to do further reading or research has ready access to pertinent sources.

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Chapter 9

Future Research Directions in Psychomotor Learning and Performance

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This chapter selectively reviews some of the current information concepts, and methods emanating from psychology, biomechanics, engineering, applied mathematics and the neurosciences as they relate to psychomotor learning and performance. Where appropriate, current trends are identified and possible future directions are suggested. The material reviewed and discussed is organized under three main headings: (1) increased emphasis on the study of cognitive processes; (2) more attention to information from the neurosciences; and (3) greater use of concepts and techniques from engineering and applied mathematics. These headings are, indeed, the three broad directions being proposed for psychomotor learning and performance research in the future.

INCREASED EMPHASIS ON THE STUDY OF COGNITIVE PROCESSES

Over the course of the past 50 years, the study of psychomotor learning and performance has emerged from beneath the umbrella of Stimulus-Response (S-R) behaviorism and adopted an information processing approach. Fundamental to S-R behaviorism is the belief that learning evolves as a direct result of the strengthening of associative bonds between specific stimuli and responses; the role of the learner being that of a passive storehouse of information. In contrast, the information processing approach assumes the position that the learner actively processes information by organizing, storing, and retrieving it in a manner which is both meaningful and appropriate to the task being performed. While largely oriented toward the movement response itself at the outset, motor skill researchers have in recent years begun to focus more upon the cognitive processes associated with the production of movement responses. Particular attention is being directed to the way in which movement information is organized, operated upon, and retained in memory.

Memory and Levels of Processing

In its most simple form, the information processing model proposes that information elicited from the environment proceeds along well-ordered pathways, through clearly defined stages such as a preattentive storage area, often referred to as short-term sensory storage, into a limited capacity store (short-term memory) which, if repeated often enough is transferred into an unlimited capacity store (long-term memory). In the late sixties and early seventies the representation of information flow through well-defined stages was more critically reviewed (e.g., Murdock, 1972; Tulving & Patterson, 1968) and there emerged an alternative framework which described the processing of information within the human organism in terms of levels rather than stages.

Dissatisfied with the way in which capacity, coding and forgetting characteristics were presented in the earlier stages of processing models, and impressed by Treisman's (1964) "Levels of Analysis" theory of attention, Craik and Lockhart (1972) developed just such an alternative framework which advocated a levels of processing approach to the study of human memory. Central to their conceptual framework was the notion of processing "depth," whereby incoming information progressed through a series of hierarchy of processing levels involving a greater degree of semantic analysis. The depth to which information was analyzed was purported to determine the strength of the memory trace developed and the subsequent quality and quantity of information retrieved. While these processing levels must be conceivably divided into stages (i.e., sensory analysis, pattern recognition, etc.) Craik and Lockhart preferred to envisage such processing levels as a "continuum of analysis."

Since 1972, this original concept has been modified to a large degree, both by the authors themselves (Craik, 1979; Craik & Jacoby, 1975; Jacoby & Craik, 1979; Lockhart, Craik & Jacoby, 1976) and a number of other investigators (Anderson & Reder, 1979; Battig, 1978; Battig & Shea, 1980). Empirical data revealed that the level of retention and subsequent performance could no longer be explained solely in terms of depth of processing. Additional processing mechanisms such as elaboration, distinctiveness, congruity and encoding-retrieval compatibility also contributed to effective memory, along with the nature of the information to be processed and the context in which it was to be used.

When one refers to elaboration of processing, a quantitative increase in the amount of information is implied, as opposed to the qualitative properties of processing depth. Indeed, Anderson and Reder (1979) see the process of elaboration to be the critical determinant of long-term retention in that it increases the redundancy of the to-be-remembered items such that the memory trace for the task being learned is strengthened. As compared to Craik and Lockhart's (1972) original contention that the greater the depth of processing performed, the better the retention of the skill learned, Anderson and Reder believe that better processing is generated as a consequence of the number of elaborations of the original input.

The mechanism of distinctiveness is largely descriptive and may be viewed as the degree to which one event or piece of information differs from another. Craik (1979) believes the depth to which a stimulus is processed and the amount of elaboration afforded it will determine its distinctiveness. Fisher (1981) and Winograd (1981) suggest that such a relationship exists between elaborative and distinctive processing and, therefore, are in agreement with Craik's supposition that increased elaborative processing may increase the probability of distinctive processing.

The first of the remaining properties, namely congruity, refers to the extent to which an event fits into current structures and schemas, whereas encoding-retrieval compatibility describes the consistency of the conditions under which information was originally encoded with those under which it was retrieved. As a result of the research emanating from the original framework of levels of processing which was postulated by Craik and Lockhart, the true complexity and context specific nature of human memory emerged. Certainly, it became evident that depth of processing alone was insufficient to promote better learning and retention of stored information. Rather, as described by Battig and Shea (1980), a rich interaction of all processing mechanisms is more likely to strengthen the remembrance of an event or item and thus facilitate retrieval than a single mechanism operating in isolation from the rest. Indeed, a remembrance based on a single mechanism seems unlikely given the complex nature of human memory. To these five mechanisms, Battig (1978) added two additional properties: one was contextual interference and variety and the other was multiple and variable processing. These two properties were empirically demonstrated to positively enhance retention and retrieval of movement information: in the motor domain by Shea and Morgan (1979) and later, theoretically formalized by Shea and Zimny (1983).

In the first attempt to empirically validate Battig's (1979) conceptualization of memory and his contention that practice under conditions of high contextual interference would promote more elaborate and distinctive processing of the task to be learned while facilitating transfer to novel tasks, Shea and Morgan (1979) used a task in which subjects were required to knock down three of six barriers in a specified sequence following the onset of an appropriate stimulus light. Random and blocked trial conditions were used to simulate conditions of high and low contextual interference, respectively. Subjects performed three randomly presented barrier sequences in the random condition and only one barrier sequence in the blocked condition. Results indicated that subjects performing under high levels of contextual interference exhibited superior recall of the motor task following a short-time (10 minutes) and long-time (20 days). In addition, superior performance was exhibited by the high interference group when transferred to novel tasks of increasing complexity. The use of multiple and variable processing strategies and the greater elaboration by subjects performing under conditions of high contextual interference were advanced as explanations for the superior recall capabilities and performance levels of the high interference group on more complex tasks. Shea and Morgan's findings have more recently been replicated and extended in research conducted by Lee and Magill (1983), who also demonstrated the facilitative effects upon learning and retention of non-repetitive practice schedules which forced the learner to adopt more "cognitively effortful problem solving activities" (p. 744).

Perhaps the greatest strength of the levels of processing approach, as opposed to the earlier stages of processing models lies in its plasticity, which provides for modification and/or elaboration of its existing structure as new research findings emerge or additional methods of processing are discovered. One major goal of future research will be to better understand the mechanisms that humans use to process information. Models and theories formulated must be flexible enough to adequately describe the multitude of information processing strategies used to enhance retention and facilitate subsequent performance and at the same time account for the context specific nature of information processing. One of the "battle fronts" of future research will be to determine the nature of the influence of context on the type and number of processing mechanisms utilized. Such research will move researchers closer to a comprehensive theory of human information processing.

Organizational Processes and Strategies

Organization of incoming stimulus information has been shown to facilitate the retention and subsequent recall of verbal skills (e.g., Tulving, 1968), and research conducted in the area of psychomotor learning and performance has revealed similar findings. The organization process is believed to involve a hierarchical arrangement of information into units or "chunks." Essentially, the learner imposes order upon stimulus items for the purpose of establishing meaningful relationships between them. What strategies does one use to impose order and/or meaning upon incoming information to facilitate the learning, recall and performance of a motor response? Gentile (1967) found that subjects differentiated test positions in an arm positioning test without vision by first identifying "anchor points" at the extreme ranges of possible test positions. Then they encoded intermediary positions in relation to the anchor points. Nacson, Jaeger and Gentile (1972) found that providing verbal instructions/labels which described the various categories of test positions to be presented provided subjects with the means to organize their positioning responses more effectively. Breaking with the tradition of the usual short-term memory paradigm in which subjects performing an arm positioning task without vision are asked to move to an experimenter-defined distance and endpoint, Marteniuk (1973) and Stelmach, Kelso and Wallace (1975) employed a preselection paradigm in which subjects were free to choose their own criterion movement distance and endpoint. When compared to the experimenter-determined method, recall of target positions was much more proficient in the preselection paradigm. They proposed that the preselection method resulted in superior recall because it enabled subjects to organize the movement distance and endpoint in advance of the cue to move, which could not be done in the experimenter-determined method. In other words, the preselection method allowed subjects to organize the entire response prior to the cue to move whereas the other method did not. Nacson (1974) and later, Christina (1978), Diewart and Stelmach (1978) further supported the importance of such organizational factors in psychomotor learning and performance. Using an arm positioning task without vision, Diewart and Stelmach demonstrated that when provided with the opportunity to subjectively encode and organize stimuli into more meaningful relationships, adult subjects continued to improve despite the withdrawal of knowledge of results. Utilizing the same task used by Diewart and Stelmach, and similar experimental procedures, Canabal-Torres, Christina and Lundegren (1984) also found the organization of movement information to be an important variable for effective recall among children. Although Canabal-Torres et al. did not find subjective organization to be superior to experimenter imposed organization, those children provided with the opportunity to organize incoming information exhibited more effective recall of positioning responses.

It is clear that the study of organizational processes is important to a better understanding of psychomotor learning and performance. Future research on this topic might begin to look at (a) the way in which organization differs across various task situations; (b) the types of the organizational processes formulated; and (c) the manner in which such processes develop. The few studies reviewed provide only a beginning. What is needed in the future is a systematic research effort investigating how humans organize movement information for effective psychomotor learning, retention, and performance of tasks that are more ecologically valid than positioning responses. Hopefully such a research effort will eventually help researchers and practitioners to better understand the nature of the organizational processes used by learners and the conditions under which such processes are optimized.

Attention and Automation

One has only to view a competent craftsman, athlete, or artist perform a well-learned skill to see that movements tend to be devoid of effort and indecision. Indeed, on some occasions, highly skilled performers are capable of performing two or more concurrent tasks. Unlike the beginner or novice who expends much mental and physical effort, skilled performers appear to move in an automated manner, with little attention required to ensure successful performance. Indeed, the shifting of movement control from a conscious to an automatic mode has been addressed by numerous motor skills researchers (e.g., Adams, 1971; Fitts & Posner, 1967; Schmidt, 1975, 1982; Stelmach & Larish, 1980).

In two recent articles, Stelmach and Larish (1980) and Stelmach and Hughes (1983) attempted to solve two problems. The first was the nature of the operational characteristics of automation and the second was the variables which influence the development of automation. After proposing that automation is not accounted for only by a model of attention and that recognition of other equally complex phenomena are required, Stelmach and Larish developed a somewhat different perspective with regard to motor skill automation. As a consequence of repeated exposure to a stimulus or set of stimuli, it was hypothesized that one develops an automatic sequence of movements which are triggered immediately on presentation of the appropriate stimulus. Such a sequence is directly accessed from long-term memory and put into operation without attention. Only in the case of alterations in context or changes in the structure of the habituated action, as might be experienced when driving someone else's car for the first time, is such attention required that processing seems to occur at more conscious levels.

Schneider and Fisk (1983) proposed a notion similar to that of Stelmach and Hughes and suggested that automatic processing is developed as a result of consistent practice. Unique to Schneider and Fisk's approach is the idea that controlled processes, which are subject controlled and demanding of conscious attention, not only contribute to the development and performance of automatic productions, but are also important in the performance of skilled behavior. As defined by Schneider and Fisk, the term "production" is to be equated with a generalized-action rule which invokes a given action once appropriate stimulus conditions are satisfied. The complementary interaction occurring between these automatic and controlled processes would seem to add flexibility to an otherwise rigid automatic system. Two functions thought to be performed by controlled processes in skilled behavior are (a) the maintenance of strategy information in short-term store which enables a performer to shift from one automatic production to another when confronted with a change in the original operating conditions, and (b) the maintenance of time-varying information in a short-term store which cannot be incorporated into the more fixed automatic process.

Given that the new approach to the study of attention and automation of motor skills just outlined is still largely theoretical in nature, one primary aim of future research is to develop a more comprehensive knowledge base with respect to the nature and operation of both automatic and controlled processes. One issue of particular interest and deserving of greater attention concerns the degree to which controlled processing resources must be made available in order to increase the flexibility of skilled performance. Assuming that automatic productions are difficult to counter (Schneider & Fisk, 1983) and will execute even when the subject does not consciously intend for the behavior to occur, any counter to a spontaneous change in the performance environment once the automatic sequence is initiated could not be achieved unless a controlled/conscious mode of operation were readily available to avert an otherwise incompatible response. One has only to watch skilled performers in action to realize that a great deal of inherent flexibility exists within their seemingly automatized movement productions. The nature of the mechanism and the way in which it is juxtaposed with an automatic sequence should be a target of future research.

Plans of Action

Having discussed some of the current trends in thinking with regard to the way in which specific information processing mechanisms function, it is now appropriate to discuss the more recent efforts to integrate these specific functions into more comprehensive theories and models which attempt to describe the way in which the human organism receives, processes and acts upon external stimuli or internally generated goals in a multitude of varied contextual situations. Beginning with Adams' (1971) closed-loop theory of motor learning, which relied heavily upon feedback based learning, interest then shifted towards the notion of a schema which enabled the learner to apply a small set of stored rules to a variety of movement-related skills (Schmidt, 1975). While feedback was important for successful learning, once mastered, a movement or series of movements could be generated independent of feedback. More recently, interest and research has centered upon Theories or Plans of Action which are concerned with describing the way in which cognitive processes interact with motivation, emotion and, most importantly, action (Allport, 1980; Norman & Shallice, 1981).

In proposing a system of condition-action units which form links between sensory calling patterns (cues) and categories of action (responses) (Allport, 1980) one might draw close parallels with S-R behaviorism described earlier. Contrary to the original preoccupation with the association between the stimulus and response, however, Allport, the advocate of such a condition-action system, places greater emphasis upon the nature of the link. Given Allport's contention that such condition-action units are capable of evoking a number of different responses to the same stimulus, such units do not convey the same meaning as was implied by the original S-R bonds.

Stimulated by the idea of condition-action rules forwarded by Newell and Simon (1972) in the Production Systems model, Allport integrated these concepts into a general Plan of Action theory. Fundamental to this theory is the assumption that different categories of skilled action are controlled, at a relatively abstract level, by content specific mechanisms, affectionately referred to by Allport, as "action demons." Two important prerequisites for action are the presence of an internal GOAL and an external CUE. The mere possession of an intention to act is insufficient if the appropriate environmental cue is absent and, vice versa. Recall at this point that repeated exposure to an external stimulus (cue) was believed to be sufficient to trigger a response according to behaviorist theory. The inclusion of an internal goal in the more contemporary theory is thus indicative of the desire to integrate the actions of the body with that of the mind.

While the more recent activation models represent the first positive steps towards a more cognitively based theory of movement production, many questions have yet to be answered. For example, what is the nature of the relationship between the internal goal and the external cue? Are there situations in which the intention to act might be sufficient to trigger a response? Does such a relationship change as a performer acquires skill proficiency? Furthermore, Kerr (1983) suggests that such factors as the role of intent, will, and goals also need to be resolved. These current activation models, though theoretically plausible, must now be empirically substantiated and the extent of their generalizability ascertained. The extent to which the new model is able to account for existing and new data will ultimately determine its future application to the study of psychomotor skills.

MORE ATTENTION TO INFORMATION FROM THE NEUROSCIENCES

Historically, the greatest amount of research on psychomotor learning and performance has been contributed by behavioral scientists. One has but to review the related literature generated in the first half of this century to find the strong influence that the experimental psychologists have exerted on the growth and development of this area. In recent years a significant trend is emerging in which more attention is being given by an increasing number of behavioral scientists to the research coming from the neurosciences in an effort to better understand the underlying mechanisms of motor control. Conversely, an increasing number of neurophysiologists seem to be developing a greater interest in the functional aspects of the neural mechanisms as they relate to psychomotor behavior. This developing interdisciplinary trend is likely to grow stronger in the future. The next two sub-sections overview some of the new information emanating from the neurosciences that is relevant to psychomotor learning and performance. Much more information is available, but the restrictions governing the length of this chapter do not allow it to be included. Nevertheless, it is hoped that what is presented will serve to demonstrate how important it is for psychomotor behavioral scientists to keep abreast of the knowledge being generated by the neurosciences.

Coordination of Voluntary Movement

Even the simplest of movements requires harmony among contributing muscle groups if movement is to be executed efficiently and accurately, and "unorganized convulsions" (Weiss, 1941) of the muscles avoided. The process by which coordinated sets of muscle commands are constructed and governed remains an issue to be resolved in the study of psychomotor learning and performance. Bernstein (1967, p. 127) described coordination of movement as "the process of mastering degrees of freedom of the moving organ, in other words its conversion to a controllable system." Turvey (1977) elaborated on the degrees of freedom problem by describing it as the mechanical latitude inherent in the skeletomotor system. Greene (1969) has estimated the number of degrees of freedom in the hand, shoulder, and arm to be at least 40 and possibly more. The problem of defining how a human might control individual muscles in a complex manner, mastering the degrees of freedom, has led several investigators to propose that the human central executor system controls "coordinated structures" (Easton, 1972; Turvey, 1977). Coordinative structures are muscles organized into functional combinations which work exclusively to enact a specific response with a reduction in the degrees of freedom resulting in greater coordination of the skill being performed. Easton (1972) has suggested that reflexes may be examples, or components of inherently organized coordinative structures, but this inference implies a more permanent neurophysiological structure. Could reflexes serve as the foundation upon which some or all of learned psychomotor behavior is built? This view is certainly not a new idea, but advances in the neurosciences have stimulated a reinvestigation and closer examination of the structural flexibility of reflexes. One of the problems for researchers who pursue this line of research will be to determine exactly how to design critical experiments that will generate empirical evidence which reveals the actual role played by reflexes in the learning and performance of motor skills.

A second structure that has received attention in recent years is the central pattern generator (CPG), or neural oscillator. Generally, it has been limited to specific classes of movements, most notably stereotypic repetitive movements such as locomotion (Grillner, 1975, 1981; Shik, Orlovskii & Severin, 1968). Fowler and Turvey (1977, p. 15) have argued that "commands to individual muscles would appear to constitute an inappropriate vocabulary of control" for the executor. More appealing would be a control system which utilizes coordinative structures as its vocabulary. In the case of central pattern generators, a set of "functionally" linked motoneurons control locomotion. What is so intriguing about these oscillating control systems is the fact that they may be initiated not only by commands from the cerebral cortex but also from spinal cord level sensory input (Smith, 1978). Once the oscillator has been stimulated it continues to fire, in a repetitive sequence, the motoneurons which effect the action of locomotion for at least a moderate time before subsiding. The implications from research on neural oscillators are quite challenging to existing notions of motor control systems especially when one considers that the human motor system has been thought to operate exclusively in a top-down, brain to spinal cord, hierarchical manner. Neural oscillators with the capacity to be activated by sensory input suggest control may be more heterarchical. By heterarchical we mean that the higher domains "enter into 'negotiations' with lower domains in order to determine how the higher representation of an action shall be stated" (Turvey, 1977, p. 224). Empirical support for CPG's has come primarily from surgically invasive experiments on infrahuman species and certainly further evidence of oscillators in humans remains a quest of research. However, scientific efforts to understand the coordination of voluntary movements have resulted in the accumulation of an increasing number of theoretical problems which remain to be solved.

For the performer, more degrees of freedom mean less control and stability of body segments, usually resulting in poorly coordinated movements. As a performer learns a skill, he or she may be developing some constraints over superfluous degrees of freedom allowing greater control over body limb segments. An example of this can be found in the movement characteristics of elite pistol shooters. Victor Gurfinkel, a prominent Russian scientist who has significantly contributed to the understanding of motor control processes, stated that "an essential characteristic of a marksman is his ability to stabilize his gun" (Evarts, 1979, p. 179). This characteristic was evidenced by the recordings of muscle activity of elite shooters which revealed movement or tremor in many body parts while the pistol remained virtually motionless. How might beginners develop this control? Easton (1972, 1978) suggested that new coordinative structures may be built by modifying pre-existing ones and used to execute new responses. Beginners, in the early stages of learning, probably have a smaller base of established coordinative structures at their disposal than do advanced level performers who have constructed a larger repertoire. Therefore, learning to control movements involved in types of skills which require the use of a broader set of coordinative structures, would be expected to take longer for beginners than for advanced performers.

Development of coordinative structures with large amounts of practice, such as would occur over a period of many years, may result in the structures becoming more rigid and less easily modified. This might be one reason for the inflexibility of older adults who seem less able to adapt quickly when learning new motor skills. The relationship between the amount of practice a learner receives and at what point coordinative structures become most effectively developed for execution of a skill has received little attention from psychomotor scientists and provides one possible direction for future research. Therefore it would be relevant for scientists to ascertain methods by which coordinative structures may be constructed resulting in accurate motor control, yet maintaining a certain amount of functional flexibility for modification of existing structures.

Future research probably will continue to investigate the exact nature of the behavioral units of learning such as coordinative structures. Research also must be aimed at further identifying additional patterned movements (e.g., locomotion, throwing, kicking, etc.) which might be functionally controlled by central nervous system pattern generators. Questions that remain to be answered are: a) how many actions are governed by neural oscillators; b) to what degree do learned movements make use of existing oscillatory structures; and c) how are multiple oscillator systems linked together? Research answering questions such as these will greatly enhance knowledge of the human motor system and will be beneficial to the development of the field of robotics in the design of locomotive devices.

Heterarchical Control of Movement

The control of movement continues to be investigated at many different hierarchical levels (Stein, 1982; Stelmach & Diggles, 1982; Kohout, 1976; Hatze, 1976). However, the current trend, and the trend of the future is to view action as being heterarchically organized (Gallistel, 1980, 1981; Turvey, 1977). It is now believed that higher cortical centers may not entirely control the lower nervous system centers, but instead may become involved in "coming to agreement with them" implying bidirectional control, in terms of how best an action may be performed. This shift, from viewing human action as being hierarchically controlled to being heterarchically controlled, reflects a significant trend in the theory of psychomotor performance, which until the most recent years has been considered inconceivable by many researchers.

An important concept, which can be more easily explained by a heterarchical control system, is one of motor optimization (e.g., Hatze, 1976; Cavanagh, 1976) which has been reported in mathematical modeling and biomechanical analysis of movement. Optimization is a construct which implies that the control of movement is carried out in the most efficient way possible. This might be in terms of minimal energy consumption (Cavanagh, 1976; Miller, 1979) or time savings (Hatze, 1976) and made possible through the utilization of many structural resources. From a neuromechanism point of view, neural oscillators involved in locomotion might be considered as reflecting neurophysiological optimization. If, indeed, the human control system is heterarchically organized, then the existence of lower level neuromechanisms capable of assuming control of fairly complex rhythmic action would suggest efficiency of control. A completely hierarchical control system however, would place a constant demand on cortical structures responsible for processing incoming information, selection, and execution of movement commands. Neural mechanisms, such as neural oscillators, may help to reduce this processing "work" load. Partitioning of this "work" load amongst cortical, subcortical, and spinal level mechanisms may be one explanation for how humans can effectively perform simultaneous tasks (e.g., walking and talking). Future research must attempt to account for the control of simultaneously performed tasks which suggest a heterarchical control system. Another question which must be answered deals with how optimization occurs with cognitive processes as well as the effector system upon which they are mapped. A second phenomenon on which future research must concentrate is motor equivalency. This refers to the way in which the same, or nearly similar response outcome can be elicited through a variety of neuromuscular options. In other words, there are many ways the central nervous system can issue commands to achieve the same basic movement pattern. This may be related to the optimization notion, but further research must be conducted in order to identify and correlate those characteristics which are common to both.

The mathematician Kohout (1976) has indicated that the ultimate goal of the psychomotor behaviorist should be to determine both the structural and functional hierarchies in the central nervous system and how these levels are integrated. This would seem like an ecologically valid approach, but few researchers in our field have attempted it. Many take a conservative approach and restrict their research to one particular functional level. If psychomotor learning and performance is to grow as a discipline, future research must make a more concerted effort to integrate empirical findings from multiple levels (Stelmach & Diggles, 1982). Kohout further suggests that three major problems must be overcome if adequate solutions are to be found to problems of modeling the human motor system. Lashley (1951) addressed the first problem, that being the syntax of movement. This concerns the difficulty in measuring physiological events occurring in parallel or simultaneously. Behavioral scientists have been able to resolve this problem to some extent, with more sensitive and sophisticated measurement devices but this difficulty still may be present whenever physiological measures are used to infer behavioral changes. A second problem to be overcome is that of cybernetic equivalence (Wiener, 1948) between different control systems levels. In other words, how is information communicated between different levels? An example of this might be to ask how mental representations are translated into neural commands. Finally, the problem of general coordination of multiple levels of control, addressed in detail by Bernstein (1967) must be solved. Recall that Bernstein described the basic problem as one of overcoming the superfluous degrees of freedom of a moving organ transforming the moving limb or body into a controllable system. The degrees of freedom problem has been more recently addressed by Gallistel (1981) and Greene (1982). This most intriguing topic is deficient of empirical evidence despite the fact that it is very easily observed by watching almost any skilled action. It is likely that scientists will continue to explain and study the underlying mechanisms which serve to constrain the degrees of freedom in skilled movement. This raises a question which is currently generating a great deal of interest. What are the parameters used by the central nervous system to control movements? Several factors have been suggested: Force (Evarts, 1968), length of muscle fiber (Merton, 1953), velocity (Matthews, 1972), muscle stiffness (Houk, 1979), and muscle viscosity (Stein, 1982). Stein notes that by varying the response and goal, researchers are getting a wide variety of answers as to the parameters which are most important in control of movement. Models have been proposed such as the Mass-Spring (Bizzi, Polit, & Morasso, 1976) and Impulse-Variability Models (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). The Mass-Spring Model holds that an equilibrium point between agonist and antagonist muscles determines control commands, whereas the Impulse-Variability Model proposes that the motor commands control the force and timing characteristics of movement. There have been criticisms of both models (Nichols & Houk, 1976; Stein, 1982; Meyer, Smith & Wright, 1982; Schmidt & McGown, 1980) as well as each of the other individual parameters. This further substantiates a growing belief that the central nervous system is intricately complex and capable of modifying many parameters of movement control, depending upon the demands made on the human organism (Stein, 1982). This problem is far from being solved and no doubt will continue to be of interest to researchers in the future.

GREATER USE OF CONCEPTS AND TECHNIQUES FROM ENGINEERING AND APPLIED MATHEMATICS

Concepts from engineering and applied mathematics and techniques employed in these fields have been used by a few to some extent in the psychomotor domain. This trend is not only likely to continue in the future, but probably will become more widespread among researchers interested in psychomotor learning and performance. Advances in computer technology and less expensive computers that are simple to operate undoubtedly will make this future trend possible. The following two subsections describe how some of the concepts and techniques from these two fields have been employed in the past and can be used in the future to more thoroughly understand and enhance psychomotor learning and performance.

Engineering Control Systems

Two distinct types of engineering control systems, closed- and open-loop systems, have been used as models to describe how the human motor system operates. A closed-loop system is a self-governing system (also called servomechanism or feedback system) which must include four important features to be classified as such. One feature is a system goal or controlled variable, which is the value that the system is attempting to achieve (Schmidt, 1982; Zimmerman, 1978). The second feature is feedback which is information from sensing devices (sensory receptors in humans) that travels via a feedback loop to alert the third feature, the controller or executor (the brain in humans) about the current status of the system. The fourth feature is the set point or reference of correctness (an internal standard of correctness in memory) which serves as a blueprint of the intended goal of the system. The blueprint is compared to sensory feedback produced from the response that was made in order to determine if the movements intended were actually carried out by the system. If the intended movements were carried out, no error or mismatch is detected. If they were not, an error is detected and correction is made.

Many practical examples of error correction via closed-loop control exist in psychomotor learning and performance. Think for a moment of an experienced basketball player taking a 20-foot jump shot. The intended goal of the player is to make the shot. On the final shot the player sees the ball hitting the front of the rim, and feels that the movement executed didn't feel just right. To achieve the goal on the next shot, the player issues a new set of commands which say "shoot a little higher and harder." This closed-loop system could continue to operate until the goal has been successfully achieved, and would also keep the performer apprised if at any time the goal was not being achieved.

Although a great amount has been learned about closed-loop systems control from research on theories of learning (e.g., Adams, 1971; Schmidt, 1975), there is still much that is not known. For instance, researchers have not yet discovered how feedback from multiple sources is combined into an ensemble (Schmidt, 1982), integrated with previous experience, and used to control movement. Future research probably will be aimed at ascertaining the locations and pathways through which multiple feedback sources are used by the central nervous system in generating action. Another problem is that of static versus dynamic closed-loop systems (Zimmerman, 1978). The distinguishing feature of a static system is that the internal reference of correctness or intended goal never changes. Is it possible for this type of servomechanism to exist in the human motor system? Perhaps, especially if certain types of reflexive actions are permanently hardwired to a particular threshold level. Then any action exceeding the boundaries of that threshold would result in a reflex response. However, in complex human psychomotor behavior, the intended goal often must be altered in order to adapt to the changing environment. It therefore seems intuitive that the internal goal and/or reference of correctness would be dynamic in nature. Zimmerman further suggested that a dynamic system must have embedded certain adjustment characteristics, such as the ability to alter the reference of correctness (change the set point) and to modify the gain, that is, the amplification factor of the controller. An example of dynamic adjustment would be the ability of cerebral centers to change the discharge rate of motoneurons as a function of some unit change in the length of muscle fibers. Any malfunction of this system could result in extreme gain (amplification) and instability or oscillations of the motor response. This may be one reason for the tremor associated with movement seen in people suffering from Parkinson's Disease or Huntingtons Chorea.

An open-loop control system has the commands, which are to be sent from the brain to the muscles, structured in advance and executed independent of feedback. Feedback may exist in the system, but the central nervous system doesn't have ample time or chooses not to process the feedback. Therefore the response is produced by prestructured commands and such a response is referred to as being programmed. The rapid downswing of the hammer to strike a nail "hard" is an example of a programmed response.

It is most likely, however, that the human motor system operates under a hybrid or integrated control system and therefore makes use of both open- and closed-loop systems at one time or another. Whether the system used is open or closed probably depends on which one is most efficient for the completion of the goal. It is also possible for open- and closed-loop systems to be embedded within each other (Schmidt 1980, 1982). It is known that early in skill learning, responses tend to be feedback dependent and executed quite slowly. Later in learning, as the skill level improves, the performer seems to be able to integrate the appropriate commands in such a way as to develop motor programs or plans of action that operate predominantely independent of feedback (Christina & Anson, 1981; Keele, 1981).

Physical and Mathematical Modeling

Physical modeling, discussed by Miller (1979), uses a biomechanical approach to the study of human motion. This type of modeling involves the imitation of a person's performance for the purpose of analysis or prediction. Physical modeling places emphasis on the descriptive characteristics of human motion, such as the relationship between body segment planes, axis of rotation, joint movement, etc. Computer simulation is one growing trend, which involves the use of computers to monitor motor performance and provide immediate feedback at a very sophisticated level (Atwater, 1980; Tarde, 1980). The development of new techniques such as: 1) polarized light goniometry (Grieve, 1969; Mitchelson, 1973, 1975; Reed & Reynolds, 1969), 2) automatic image analysis in which an image is scanned by a computer (Winter, Greenlaw & Hobson, 1972) and 3) a light spot position measurement device utilizing optoelectronics, such as the SELSPOT System (Lindolm, 1974; Woltring, 1974, 1975) have greatly advanced this line of applied research.

Tarde (1980) has described a sophisticated set of cameras and computer interface which is capable of providing a detailed analysis of a golf swing in seconds and provide feedback about such variables as clubhead speed, swing path, position of the clubface at impact, the angle of attack, hit location, ball speed, backspin, side spin, launch angle, distance and carry, carry and roll, and deviation from the true swing line. For the trained teacher/instructor, research of this nature could lead to a greater understanding of the necessary features of information feedback, and result in the development of more efficient methods of facilitating a learner's performance. The biggest drawback at this time is simply cost. As computers become less expensive, the possibilities for their use as training tools appear to be almost limitless. Christina and Lambert (1984) recently developed a portable, low-cost prototype instructional device which employs a sonic digitizing system interfaced with a microcomputer to measure gun barrel movement in relation to a target and provide immediate feedback in the form of a visual display tracing of the movement on a television monitor to the coach and shooter. Inexpensive systems of this type further advance the application of computer simulation techniques and make their implementation in many aspects of psychomotor learning and performance possible.

A second type of modeling is mathematical; that is, developing mathematical equations, or algorithms, which attempt to describe human behavior. This approach has proven beneficial to researchers across disciplines and it is now being used in the study of psychomotor behavior. Domotor (1976) discussed the use of mathematical modeling of psychological phenomenon. Domotor emphasized that although it is extremely difficult to accurately model a large complex system, such as the human motor system, much can be gained from modeling sub-components of the system. Despite the fact that imitation results in oversimplification, the success of any modeling process should be based on whether this conceptual tool has allowed specific problems to be resolved. The outlook for further development of this technique appears to be reasonably good. Regardless of its limitations, much can be gained by using mathematical modeling as a scientific method by which researchers can ascertain the unknowns of real life situations.

What types of mathematical modeling have been done with respect to psychomotor behavior? In recent years mathematicians have had greater success in their attempts to model subsystems of the more complex human motor systems. Several types of mathematical models have been developed: Locomotion (Townsend & Seireg, 1972), temporal precision (timing) of various types of motor responses (Wing, 1977), and general hierarchical organization of psychomotor control (Hatze, 1976; Kohout, 1976). Also attempted have been models for perception and selective attention (Swets, 1964; Tonge, 1976), and human psychomotor learning and memory (Ono, 1966; Domotor, 1976; Schutz, 1980). Greeno and Bjork (1973) published an article on human learning which included discussion on strategy modeling and parameter estimation.

Two major benefits may occur from the use of mathematical modeling. First, the growth and development of the field of Artificial Intelligence (AI), which emerged from the work of mathematicians and their models, has the potential for increasing our understanding of the human motor system. Work from the AI field may provide some theoretical basis from which psychomotor behaviorists may expand the study of cognitive processes responsible for motor response production. A recent article by Raibert and Sutherland (1983) provides an excellent example of the use of AI. The basic concept is that many machines imitate nature in their functioning. Many of the structural features of an airplane, no doubt, were taken from observation of birds in flight. Raibert and Sutherland are attempting to develop a six-legged walking machine, and a two-dimensional hopping machine. The goal of their research on the hopping machine is to attempt to conquer balance and motion problems associated with the control of a hopping motion through the construction of servomechanisms. The three servos required by a dynamic hopping system would be one to control height of the hop; a second to control the balance of the machine by positioning of a foot just prior to landing; and a third to keep the body in an upright position. If AI scientists are able to solve some of these problems, great potential exists for increasing our understanding of the human motor control system. From a control standpoint, AI has already aided in the development of prosthetic limbs, and human organ operational devices, such as the mechanical heart.

A second potential benefit of mathematical modeling involves computer simulation and monitoring of motor performance, which could allow a more sophisticated and comprehensive approach to the study of psychomotor learning and performance. Computer simulation is also an area through which mathematical modeling may be used to study the human motor system (Schechter, 1971). Simulation represents a more advanced attempt to vary internal and external movement parameters involved in the control of action and determine how these alter the environment. Inserting different values or parameters in mathematical equations for models enables scientists to observe how a subsequent response is affected. For instance, considering the golf simulator described earlier, if the goal was to analyze the effect of clubhead speed on distance and roll, different speeds could be inserted into a computer algorithm and the resultant distance and roll values obtained. Two benefits of such mathematical modeling are (a) reduced time and cost in experimentation; and (b) minimized risk when testing could be potentially dangerous to human subjects. It seems likely that the use of mathematical modeling and computer simulation to study psychomotor learning and performance will be on the increase in the not too distant future.

SUMMARY

Three broad directions of future research were proposed: 1) an increased emphasis on the study of cognitive processes and strategies, 2) more attention to information from the neurosciences, and 3) a greater use of concepts and techniques from engineering and mathematics involved in psychomotor learning and performance.

Using motor tasks that are more like those found in the real world than in the laboratory, more needs to be known about (a) how individuals organize, store, and retrieve movement information; (b) the nature and operation of attention and automation in the development and control of skill movements; and (c) the nature of cognitive action theories in terms of how factors such as a person's intent, internal goals, external cues, context, and motivation function in the learning and performance of skilled movements.

The second future direction identified was that more attention be given by a greater number of researchers to information being generated by the neurosciences. Research investigating topics such as the concept and development of "coordinative structures," and the heterarchical control of movement is likely to produce information that is particularly relevant to those interested in understanding the mechanism underlying the learning and control of skilled movements.

The third future direction was a greater use of concepts and techniques from engineering and applied mathematics. For example, recent advances in computer technology and education, and less expensive computers will make it possible for many more researchers to become involved in using both physical and mathematical modeling of psychomotor performance. Such modeling can (a) provide an accurate and detailed description of a skilled performance; (b) provide immediate information feedback about a performance to the instructor and performer; and (c) serve as a technique for studying skill in a more comprehensive way which has great potential for increasing our understanding of how individuals learn and perform skills.

Those researchers who choose to follow one or more of the future directions that were proposed, however, would be wise to keep two things in mind. First, as Battig (1978) once advised, care must be taken not to treat psychomotor learning and performance as a subject disconnected from anything verbal or cognitive. And second, individuals being studied should be viewed as "active processors" of information who employ a wide variety of cognitive processes and strategies when they learn, perform, and retain psychomotor skills. The earlier notion that individuals function as "passive storehouses" of information is no longer tenable.

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REACTION TO CHAPTER 9, "FUTURE RESEARCH DIRECTIONS IN PSYCHOMOTOR LEARNING AND PERFORMANCE"

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The improvement of psychomotor skill theory and instruction demands a continual search for new information on the part of both the practitioner and the researcher. The interrelationship between the researcher and the practitioner is a two-way street which must be expanded and improved to increase communication and understanding of both basic information and to improve the teaching of psychomotor skills.

There must be an exchange of information, theories, and techniques which moves in both directions on the theory-application continuum. The research community can extract specific techniques or approaches from the practitioner's realm and use it as a basis to develop research. The practitioner, on the other hand, utilizes the knowledge base developed by researchers to improve the quality of psychomotor instruction in a specific setting. The practitioner, in this case the Industrial Arts teacher, must strive to maintain an active surveillance of the theory base to insure effective instruction. Additionally, he or she must be aware of the effectiveness of the strategies used in order to identify existing or new techniques which result in improved instruction. If these effective strategies or techniques can be identified and tested in a quasi-research situation, the effectiveness of the technique can be identified in a non-quantified basis. This information can be translated into an experimental setting and used to develop and verify theories or instruction techniques.

The Industrial Arts instructor should keep abreast of current learning theories and should design his instructional methodology and techniques to reflect the theories. It is a quantum jump from an experimental setting with rigidly controlled variables, specifically identified or designed tasks, and a strong evaluation system to a dynamic classroom where the variables are constantly changing, the tasks are highly complex and an evaluation system is fraught with inherent restrictions. However, the instructor should consider the utilization of a theoretical base and design an instructional program that is based on the research-developed constructs. Examples of how the teacher could approach the problem are outlined in the following paragraphs.

By nature, "theory" is nothing more than a way of describing events, phenomena, and behavior that it will allow the researcher to predict how and/or why a particular event or phenomenon occurs. As is evident in the foregoing chapter there are several different research camps using different models and/or explanations to quantify the way people learn psychomotor skills. Each of these models grows out of a separate logical pattern of thought and empirical data base. These theories may be related in structure to each other or be diametrically opposed. While it is possible to debate the merits of each of these theoretical approaches, the practitioner should work to utilize the findings of specific research within each of these theoretical bases as information which he or she can use to improve the quality of instruction for psychomotor skills. By keeping abreast of current literature the practitioner can identify variables and/or techniques which have been developed to explain a specific theoretical approach.

An analysis of the information in the preceding chapter provides a great deal of information on specific variables in psychomotor learning and reinforces information about learning variables we have been aware of for a considerable time. These include factors such as elaboration, distinctiveness, depth of information, contextual interference, learner imposed order, task automation and task sequencing. This listing of factors or variables in psychomotor learning can provide powerful cues which can be used to identify improved methodology or technique in the practitioner area.

Cognitive Processes

The development of information or knowledge inherent in the formation of concepts should be based on the elaboration of the information. The concept of "walnut wood" is different for each individual based on their background. For the average person on the street the term "walnut" will mean a brown colored wood. For the student who has received information on the structure of walnut, experienced its working properties, applied various finishes, and used a variety of cutting tools to form objects, the concept will be much stronger and will provide a greater understanding of the term "walnut." However, if the student is exposed only to walnut he will develop a limited understanding of the term "wood." The student exposed to a variety of experiences which will help provide the elaboration will develop a broader understanding of the term wood. Anderson and Reder (1979) indicate the memory trace (for recall) will be strengthened through elaboration. The increased amount of information provided in the development of the walnut concept will lead to the development of better recall of the specific concept. The comparison of the wood species and the associated properties will provide the distinctiveness of the information. Fisher (1981) indicated that elaborative processing will increase the distinctiveness of the information processed.

Organizational Processes and Strategies

A large amount of the content of Industrial Arts classes is psychomotor in nature. The development of skills requires mastering highly complex movements designed to move a tool or control the movement of a piece of equipment. The movements of an individual who has learned the task become fluid, with each movement, controlled both by location information that is part of the total movement and corrective information received through perceptual input. The teacher should plan the presentation of instruction to reflect the relationship of stimulus and performance.

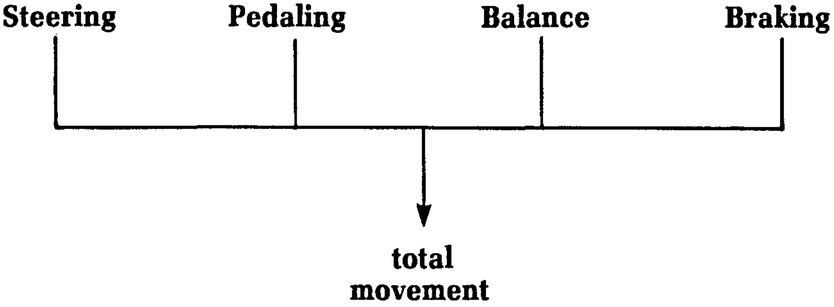
The psychomotor skill needed to properly manipulate welding equipment is an example which can be used to explain this concept. The teacher providing instruction should analyze the visual, auditory and kinesthetic perceptual cues that are required to effectively control common welding equipment. These cues and their relationship to corrective action as well as the welding requirements should be presented to the student in a well structured approach. The instructor should ask (and answer) the following questions. What is the correct starting position? How can this information be presented in relationship to kinesthetic cues? Can a system of locating this position be established so that it reflects body positioning as well as the process requirements? Are the perceptual cues organized and ordered so that the student is able to establish well developed relationships between cues which help him learn the information more effectively? The instructor should identify the relevant cues and structure the cues so that the student will be able to identify the cues and understand the interrelationship that exists.

Attention and Automation

As the student identifies the perceptual cues and the corresponding physical positioning and the relationship of these components, he/she should be given the opportunity to practice the movements until they reach automation level. The performance of very high level complex tasks becomes routine to the individual who has mastered the task to the automation level. The movements involved in the task become more rigidly controlled, which allows the individual to receive more effective perceptual information which can be evaluated and corrections incorporated in the task performance. This example is directly observable in the operation of an automobile. As the control of the auto moves over into the automation phase, the operator reduces the amount of time needed to concentrate specifically to control the car thus freeing time to make observations about the situation and allows the operator to make compensations which will improve the overall performance. The operator, during the developmental stage, must spend too much time controlling the car and will not spend as much time evaluating road conditions.

Coordination of Voluntary Movement

Observation of a child learning to ride a bicycle provides an excellent example of psychomotor learning in which several distinct movements are brought together in a coordinated effort; these include utilization of gyroscopic effect for balance, braking, pedaling and steering. When each of these components is considered independently they do not appear to be difficult to master; however when considered as a coordinated effort, the task becomes more complex. If, as Fowler and Turvey (1977) theorize, a coordinated control system best defines psychomotor movement, and as Easton suggests, new coordinated movements are structured and grow out of pre-existing coordination systems — the learning of new tasks should be analyzed and structured to develop a learning sequence that is structured on existing systems. If bicycle riding is used as an example, the learning of the total coordinated system could be structured as follows.



As the learning sequence is set up, each of the components should be analyzed to decide if the subsystem is part of the learner's experience. For the majority of children the acts of steering and pedaling exist due to experiences with a tricycle. If balance and braking can be taught as separate skills, the learner could concentrate on the development of a coordinated effort. By carefully structuring learning so that it is based on pre-existing systems and subsystems the learner could be more effectively directed to specific tasks and simplifying the amount of coordinated effort would reduce the complexity of the task.

Engineering Control Systems

Over the past few decades there has been a tremendous amount of research in manufacturing to develop cutting, forming and assembling machines which do not need to be directly controlled by human hands. This began with the card-operated looms and has moved to industrial manufacturing equipment that is controlled by computers. One of the major goals of this research has been the development of manufacturing equipment which could sense variations of the process which fell outside the quality control limitations established for the process. By utilizing a variety of sensing devices and feedback systems, this computer control allowed the manufacturing equipment to correct process deviations and maintain a more effective quality control system. The theoretical constructs and models which were derived from human behavior were tested and developed into a highly effective system that has reduced the cost of manufactured goods in this country.

An Industrial Arts instructor, working with psychomotor skill learning, must on a daily basis deal with a variety of psychomotor skills. The skills typically are used by the student to manipulate tools and/or equipment. The skills may vary from very simple to very complex. An Industrial Arts instructor preparing for a unit of instruction should analyze the particular motor skill or skills involved in the unit and develop instructional activities that result in the most effective learning. The teacher, in preparation for the lessons, could consider the theoretical base for feedback systems and consider the following items:

1. Identification of the specific movements for the psychomotor task under consideration.
2. Identification of the cues which are used for correction of movement.
3. Identification of the cues used for location reference.
4. Feedback information based on these cues and its effect on compensation.
5. Controlling compensation to avoid over-compensation.
6. The amount of repetition required to achieve the desired skill.
7. The level of psychomotor skill required to complete the task at hand.

If these components are considered in relation to the theoretical background, the instructor should be able to provide more effective psychomotor instruction. It is obvious that the Industrial Arts instructor cannot spend the time to do a complete analysis on every movement that is utilized in a course or a unit of instruction, he can complete this analysis for one task and identify the more crucial factors which could then be integrated into the planning required for additional psychomotor skills. For particular types of tasks he may find that location referencing is very critical; and in a different set of tasks such as welding, the feedback and compensation factors become very important. An Industrial Arts instructor should identify a theoretical base most applicable to their situation and utilize it as a model for the development of psychomotor skill learning. As was indicated earlier in the discussion, the instructor should remain alert to additional development in psychomotor skill theory and convert these research findings into a practical application where the variables are dynamic.

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