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Aptitude Theory: Yesterday, Today, and Tomorrow

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The concept of aptitude is reviewed and reconstructed. Its original sense of reciprocity between person and situation and appropriateness of person–situation fit is restored. Modern interpretation thus emphasizes readiness to learn in particular instructional situations and recognizes conative and affective as well as cognitive sources of aptitude. Limitations of old aptitude theories are noted. Requirements for new aptitude theories are listed. A new conceptual language for aptitude theory is suggested by the Thorndike–Thomson sampling theory, Gibson's (1966, 1979) affordance theory, and Simon's (1969) artifact theory, in combination with implications from current research.

Aptitude is an old term for an old concept still widely used, but also widely misused and misunderstood in much scientific, professional, and public parlance today. I believe it to be a central concept for educational psychology (so did E. L. Thorndike, although he seems not to have used the term), and for many other psychologies as well. In educational, industrial, engineering, clinical, counseling, and school psychology, researchers and practitioners alike face problems of aptitude every day, whether or not these are recognized or labeled as such. Although I concentrate here on educational issues, it is helpful to keep the larger sphere in mind, because thinking of aptitude only in education can lead us into local traps.

This article addresses three interrelated questions: What is aptitude? What form might theories of aptitude take? How can we describe and understand aptitude in research on learning, teaching, and instruction? These broad questions go back to the ancient Chinese and the Israelites and can also be traced through the ages in many European philosophies (Snow,

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1982). However, they have been badly distorted, in my view, by English-language psychology in this century (Snow, 1991b). Thus I first review and contrast old and new thinking on these questions. I then propose a common form for conceptualizations of aptitude across this broad front, and define a domain called *aptitude theory* within the framework of a person–situation interactional paradigm. The result is to suggest that a radical departure from yesterday's styles of theory and research has long been needed and has been taking shape in recent years; this leads to some projections about the nature of aptitude theories for tomorrow.

RECONSTRUCTING THE CONCEPT OF APTITUDE

Definitions New and Old

Aptitude is a present concern in virtually all goal-directed human activities; whenever one thinks about the antecedents of observed individual differences in some valued goal attainment, some concept of aptitude is needed. The concept is especially close to readiness (as in reading readiness), but also to suitability (for a purpose or position), susceptibility (to treatment or to persuasion), and proneness (as in accident proneness). All these concepts carry the implication of predisposition for differential response by persons to some situation or class of situations. The common thread through these and other related terms is potential—a latent, present, inferred quality or power that makes possible the development, given specified conditions, of some further quality or power, positive or negative.[1] The person–situation interaction implied by this concept is especially to be noted. Aptitudes are initial states of persons that influence later developments, given specified conditions. Furthermore, they are initial states that are not merely correlates of learning, but rather are propaedeutic to (i.e., needed as preparation for) learning in the particular situation at hand. The combination of aptitude and learning in this situation is then propaedeutic to later learning in related situations; thus, learning and aptitude development are cumulative.

The term *aptitude* came to us from Latin via French, and in various early writings from the Roman Quintilian to the Frenchman Binet the notion of person–situation reciprocity and adaptation in the development of aptitude for later accomplishment is clear (Snow, 1982). In origin, *aptitude* means "apt, appropriate, suitable," so the definition of some particular aptitude

[1]Potentials can be negative; that is, there are aptitudes for doing evil (see Scheffler, 1985). These must be ignored in the present article, although they are also an important topic for educational psychology.

has to be situation dependent. Thus, in French usage it is associated with *apropo*. The reciprocity can be between person and person, as well as person and situation, and even in early English poetic writing this usage is apparent: consider Milton's (1643) reference to "that sociable and helpful aptitude . . . between man and woman". Note also that in much early writing the person characteristics that are apt or apropo are not limited to the cognitive, but include conative and affective characteristics as well. Unfortunately, however, in English the concept was gradually equated with intelligence and capacity through the 17th and 18th centuries. Then it was generalized in the 19th century through a misinterpretation of Darwinian theory to mean a biologically fixed, single rank order of general intellectual fitness for any situation. It was captured in this distorted condition by the mental testing movement in the 20th century (see Cronbach & Snow, 1977; Snow, 1991b).

With the growth of mental testing technology in this century, applied psychologists increasingly ignored the substantive roots of the concept. Aptitude became nothing more than the predictions made from conventional ability tests. General aptitude became synonymous with intelligence. Scholastic aptitude became synonymous with verbal and quantitative ability. Beyond this there were special aptitudes defined according to the conventional distinctions among either school subject matter or vocational domains. There might be isolated research on aptitude for mechanics, or art, or computer programming, for example. But these were regarded as atheoretical and relatively unimportant applied measurement issues. In yesterday's theoretical writing, the interpretation of aptitude differences typically relied on one or another kind of entity theory. Aptitudes were reified as things in the head of the person. They were not things actually—the old phrenology and faculty psychology had been soundly rejected (by Thorndike, among others)—but they were the products of things genetic and physiological, and they were described metaphorically as things in the head (e.g., mental energy, mental engines, functional unities, instinctive responses, and stimulus–response bonds) that the person possesses. With only a few exceptions, questions about aptitude development; the mixture of cognitive, conative, and affective differences in response to instruction; and the reciprocal, adaptive relationship between persons and situations were left largely unexplored.

Thus, through the first half of this century, and still today in some quarters, British and American psychology has limped along with this narrow and stultifying misconstrual of aptitude. In my view, this enterprise ignored Quintilian altogether, hung Darwin upside down in the closet, and then closed most of Binet in there with him.

To be fair, many of yesterday's theorists tried to write carefully about their interpretations. Spearman (1927) reviewed the pros and cons of his mental energy hypothesis and included conation in his otherwise cognitive view. Thurstone (1924, 1947) also included conative and affective states in his thinking, and saw that his functional unities might arise from many possible sources. Thorndike (1921) thought of intelligence as behavior appropriate to situations – the collective result of many learned connections developed in previous situations. He also studied relations among intelligence, achievements, attitudes, and interests. Thorndike's view was least like an entity theory, and I shall return later to a version of his connectionism when considering theories for today and tomorrow. Some of yesterday's applied psychologists, notably Bingham (1937), even held to the original definition of aptitudes as aspects of personality that signify readiness to profit from particular situations. But the picture of aptitude most psychologists and educators carried around with them was an entity theory of a fixed, single rank order, general-purpose cognitive trait called *intelligence*.

It is strange to note, furthermore, that as the original concept of aptitude lost its meaning in English, the concept of readiness gained this meaning (which it did not have in English to begin with). By the 1950s, readiness was being defined as

> preparedness to respond . . . a state or condition of the person that makes it possible . . . to engage profitably in a given learning activity. . . . it is a composite of many personal qualities and conditions and differs from one learning task to another. (English & English, 1958, p. 441)

In particular, readiness for reading was

> the totality of personal factors conducive to satisfactory progress in learning to read under given conditions of instruction. . . . the relevant factors may be intellectual, emotional and motivational, or physiological. Both general maturation and effective specific previous experiences play a part. A child may be ready for one kind of reading method and not for another. (English & English, 1958, p. 441)

These definitions of readiness hark back to Binet. They clearly identify a complex of properties, qualities, states, or conditions of persons (not just a traitlike cognitive unity) that enable profitable learning or development under specified situational conditions. Different composites are relevant to different learning or developmental situations, and these likely include conative and affective as well as cognitive properties. A complex reciprocity between person and situation is expected wherein a person may be ready to profit from one kind of treatment and not from another aimed at the same achievement goal.

Apparently then, as aptitude became intelligence, readiness became aptitude. But why should aptitude be defined more narrowly than reading readiness? If reading readiness is an inferred mixture of cognitive, emotional, motivational, physiological, and experiential properties expected to differ for different instructional methods, should aptitude for reading mean something less or something else? Would tests of readiness to learn from phonics reading instruction not be aptitude tests? Apparently, English-language psychology at midcentury believed that an aptitude test is merely an ability test, that one kind of test can be called an aptitude test whereas another cannot, and that the situation for which a test is supposed to indicate aptitude need not be specified beyond, for example, a special aptitude for mechanics.

In short, the term *aptitude* has fallen into such frequent misuse that Anastasi (1980) would have it abolished in favor of the term *developed ability*. In a subset of applications, her proposed substitution might serve well enough. As argued here, however, the broad concept of aptitude includes conative and affective characteristics of persons, not just cognitive abilities. Also, the concept is useful in fields of human science where aptitude or some synonym such as readiness is a concern, but developed abilities are clearly not. Think of aptitude for a particular kind of psychotherapy or medical treatment, for example. Even in education, where aptitude, ability, and achievement are most easily confused (see Snow, 1980), the broader definition is to be preferred; it allows new conceptions of aptitude for school learning to draw research attention to other personal properties such as achievement motivations, interests, and attitudes about self and school and to the mixtures of these properties that connect individual learners to particular learning tasks in different ways, profitably or unprofitably (Snow, 1986).

Some Boundary Conditions

One might object that this broad, reconstructed concept of aptitude includes too much—all possible individual differences even remotely related to learning would need to be considered. The counterargument is threefold. First, as a public stance, we ought to be persuading the world that it is wrong to think of human potential in yesterday's narrow way. Any aspect of a person that can predict his or her response to instruction ought to be examined as relevant to important personal and instructional goals. Second, as a research strategy, the concept ought to be broad enough, at least initially, so as not to miss aspects of the person that may be propaedeutic to learning in some important situation. There may even need to be as many kinds of aptitude as there are important situations. Finally, for theoretical purposes, it may be combinations of person characteristics that most need to be understood in relation to these important situations. Human beings are not lists of independent variables; they are coordinated wholes. Limiting the initial list arbitrarily risks missing important combinations.

It is thus especially important to represent in the concept of aptitude the full spectrum of individual differences related to learning. Boundary conditions are needed in some other directions, however. Two such limits are noted here. These concern the stability, malleability, or ephemerality of person and situation characteristics.

Characteristics of persons that count as aptitude ought to be those that are of lasting concern. Person characteristics that are easily changed ought not to count as aptitudes. This much is consistent with yesterday's aptitude theory. But stability is a matter of degree and thus a question for research; aptitudes ought not to be limited to those assumed to be stable. If some persons know a particular fact and others do not, the difference may predict learning. If this prediction is easily removed by teaching the needed fact to all, then initial possession of the fact is ephemeral and thus not an indicant of aptitude. On the other hand, not knowing or understanding a particular fact may be an indicant of deep-seated, ingrained beliefs or naive personal theories that may inhibit new learning over a long period. Such beliefs ought to be counted as aptitude (or in this case inaptitude) even if with substantial instructional effort the beliefs can be changed. There is thus a continuum from stable to malleable to ephemeral, and the line that bounds the domain of aptitude is necessarily fuzzy. Even when potential inaptitudes are easily remediated, aptitude research may still be needed to pinpoint what needs remediation and how this may best be done for each person in need.

Similarly, characteristics of situations that are ephemeral or superficial may produce differential learning in the short term. But if the effect is easily erased by minor changes in the situation, it too is of little lasting concern. As in the case of person characteristics, aptitude research ought to focus on the major, relatively stable dimensions along which situations vary or can be made to vary. Yesterday's aptitude theory concerned only the situational variations that defined school subject matter or vocational domains. Today's focus has added many other dimensions of instructional treatment design.

Research on Aptitude-Treatment Interaction

With this reconstructed concept of aptitude, Cronbach and I set out in the late 1960s to investigate aptitude-treatment interactions (ATI) in instructional research. Cronbach (1957) had recognized that yesterday's aptitude research was limited to demonstrations of test-test and test-criterion correlations that ignored situational variations, just as experimental research on instructional situations had ignored aptitude variations; the two approaches had to be united in the study of ATI if a new aptitude theory was to be reached. I had done some ATI research of my own (in a doctoral dissertation; see Snow, Tiffin, & Seibert, 1965). We thus joined forces to seek new theories of aptitude and new schemes for adapting instruction to aptitude differences.

The history and details of ATI research since then have been reviewed elsewhere (Cronbach, 1975; Cronbach & Snow, 1977; Snow, 1977b, 1989a), but the major conclusions we published in 1977 still hold: They can be summarized briefly in five points: (a) ATI are ubiquitous in education. (b) Measures of general ability do indeed reflect an important aspect of aptitude and show many ATI but interact especially when one treatment can be characterized as highly structured, complete, and direct and another can be characterized as relatively unstructured, incomplete, and indirect. (c) Measures of specialized abilities show relatively few ATI, but there are notable exceptions. (d) Measures of conative and affective aptitudes enter an enormous variety of ATI patterns, including some that identify the same treatment dimension of structure and completeness that enters cognitive ATI. (e) The ubiquitous complexity of ATI makes conventional hypothesis-testing methodologies inadequate, not only for ATI research, but for educational psychology in general.

We had also hoped to demonstrate a form of macroadaptation of instruction wherein students with differing aptitude patterns could be assigned on a weekly or monthly basis to alternative treatments matched to their prevailing strengths and weaknesses. This would complement the kind of microadaptation then growing from work on computerized instruction (e.g., Atkinson, 1972) and now blossoming in research on intelligent tutoring. This is still a long-range goal, and there are new demonstrations of the continuing need for it. Shute (1990a, 1990b) recently reported strong ATI results using two versions of a computer-tutoring system in electricity, each of which is also microadaptive to the minute-by-minute details of learner performance. Swanson's (1990) study of human tutoring in optics also showed ATI between alternative overall tutoring styles, despite tutor microadaptation in each; her results further suggest that tutors differ in their ability to use different overall styles. In short, then, both macro- and microadaptations seem to be needed to reach optimal instruction. And ATI concepts and procedures seem to be needed in research toward this end.

Unfortunately, through the 1980s, the complexity of the problem and failure to heed our methodological conclusions led (I would say misled) many educational psychologists to ignore or reject the ATI phenomenon. Critics said there were no ATI, or they were not replicable, or if they were it only happened at Stanford University, or they were not practically useful anyway. Most recently, in a speech heard at the 1990 American Educational

Research Association meetings, ATI was listed as just one of many fads that educational researchers had lived through and discarded in recent years.

Space does not permit me to address these criticisms here. It should be clear to anyone who studies the literature, however, that the ATI phenomenon is no fad, even if the theory and methodology used to study it in some particular era or domain proved inadequate. The just-noted Shute (1990a, 1990b) and Swanson (1990) results taken alone are enough to show that ATI are easily found and can help in understanding instructional effects more deeply, when investigators bother to include provision for this sort of analysis in their work. Furthermore, educational researchers continue to make good use of ATI-style theory and research in evaluations of large-scale educational programs (e.g., Corno, 1988; Peterson, 1988). Note also that in research on alternative psychotherapies, ATI is now a booming frontier (Dance & Neufeld, 1988; Shoham-Salomon & Hannah, 1991; Snow, 1991a). In short, aptitude research via the ATI paradigm is hardly dead.

Aptitude Constructs New and Old

Moreover, if my reconstructed definition of aptitude is accepted, then it can be said that many new kinds of aptitude constructs have been developed in the past decade, although they have not been labeled or evaluated as such. Table 1 gives a rough sketch of a network of aptitude constructs that might be candidates for research on, say, high school science instruction, particularly where treatments are expected to vary in degree of completeness, directness, and structure. Table 1 is an expansion of one part of a layout of aptitude, learning, and achievement constructs relevant to Glaser's (1976) view of instructional theory (see Snow, 1989c, 1990). It is not to be interpreted as a full classification of aptitudes, but rather as an example of the sort of provisional list one might sketch out in planning a research program. At least, it identifies most of the important kinds of student differences in prior learning and development that may need to be assessed and examined in relation to new attempts at instructional improvement in this domain.

Table 1 is a matrix of five rows (for different categories of aptitude constructs) and three columns (for different degrees of apparent stability). The aptitude constructs in the left column of Table 1 reflect relatively stable characteristics of persons that may be difficult (although not impossible) to alter in the short term. Most are well-known, molar constructs that have shown ATI with instructional treatments varying in structure and completeness. Other potential aptitude differences, in the middle and right columns, may be malleable if they are detected and addressed by instruction. All are initial states of preparation for learning, but each may carry different

TABLE 1

Aptitude Constructs That Might Be Studied in Relation to High School Science Learning

Aptitude Category	*Aptitude Constructs*		
	Stable?	*Malleable?*	*Ephemeral?*
Conceptual structures	Crystallized intelligence	Prior knowledge of physics	Believes concept X
			Explains concept X
		Quantitative ability	Computes automatically
Procedural skills	Fluid intelligence	Selective attention	Infers relations
			Detects cues
	Visualization ability	Imagery	Graphs relations
		Representation of goals	Tests hypotheses
Learning strategies	Deep versus surface processing	Heuristics, and mnemonics	Checks progress
		Adaptation of strategy	Works alone
Self-regulatory functions	Independence–flexibility	Action orientation	Protects intention
	Conformity–responsibility	Content motivation	Works extra
Motivational orientations	Extraversion–ascendancy	Investigative interest	Explores resources
	Need for achievement	Mastery orientation	Seeks explanation
	Test anxiety	Self-orientation	Worries about failure

implications for assessment and research. Some "new" aptitude constructs in the middle column may also be interpreted as constituents of the more molar constructs. The right column lists even more molecular aspects of aptitude differences; some of these may identify learning skills or strategies that can easily be changed, but some may also be seen as constituents or behavioral manifestations of constructs listed to their left.

In the rows of Table 1, five categories of cognitive and conative constructs are identified: conceptual structures; procedural skills involved in learning, thinking, and reasoning; learning styles, strategies, and tactics; self-regulatory and action control functions; and motivational orientations. I consider the first two categories cognitive, the last two conative, and the middle one a mixture. But distinctions within the resulting matrix are rather arbitrary. Knowledge, skill, strategy, control, and motivation intermingle in learning, and all have both cognitive and conative aspects. Thus, some constructs straddle categories, and some could be shifted easily to other positions. Continuing research would be expected to revise this matrix substantially, collapsing distinctions between some constructs, changing the positions of some, and adding others.

Aptitude Complexes

Part of today's problem is that we need theories of aptitude complexes, not just of single constructs (Snow, 1987). There are many hypothetical connections one might draw between the rows and columns of Table 1. But today's research tends to work on single constructs in isolation. This is sometimes a practical necessity, but it is always a severe limit for theoretical purposes. If we want to understand aptitude for discovery-oriented versus direct instruction in physics, say, or if we want to improve either kind of instruction and use aptitude information as part of the evaluation, we have to see aptitude as multivariate. At least, we have to study the most likely interrelations in Table 1 and imagine the most likely aptitude complexes. Again, human learners are not just lists of variables.

There is ample evidence that some ability and personality aptitudes enter higher order ATI. Ability × Anxiety × Treatment structure is one oft-used example (see Snow, 1977b, 1987, 1989a). But there are many other cognitive and conative interactions in need of joint study. To illustrate what is needed, let me criticize my own first ATI study as an example (Snow et al., 1965; see also Snow, 1989b). It involved some of the constructs listed in Table 1, notably prior physics knowledge (PK) and quantitative ability (QK), but also conformity-responsibility (CR) and extraversion-ascendancy (EA) as conative aptitudes.

The experiment contrasted live performance versus filmed versions of a series of physics demonstrations across a semester-long introductory college course. Achievement measures were both immediate and delayed problem-solving exercises. Performance immediately after demonstrations was superior under live conditions for students high in QK and low in PK, but superior under film conditions for students low in QK and high in PK. The effect persisted on delayed recall measures. Apparently, the live condition permitted and required the exercise of mathematical ability in understanding the demonstrations, particularly their mathematical formulations, which were often done incompletely or hurriedly by the live instructor on an overhead projector. That is, the relatively incomplete and less structured live demonstrations demanded more complex and inferential mathematical processing to comprehend, especially if PK was low. In the films, the mathematics was presented in a complete and simpler, structured fashion, well integrated with the physics of the demonstration. This was a particular benefit for the mathematically weak student with more background in science, but no benefit for the more mathematically able student who had less background in science.

However, the film–live comparison also interacted with CR and EA scales from a personality inventory (as well as with measures reflecting experience with film learning). Live instruction was best for students high in EA or low in CR; film instruction was best for students with the opposite patterns. The results were clear for immediate but not delayed measures. The interpretation was that the film condition had an adverse effect on learning in some individuals because it removed the active "interpersonal" character of instructor demonstrations and fostered a passive "spectator" state of mind. Ascendant, self-assertive, more socially dominant personalities were frustrated by the private nature of the film learning tasks whereas those described as relatively irresponsible were allowed to escape mentally from learning in them. The effect did not show on delayed measures because the intervening instruction allowed those who did not get the film messages to recoup their temporary losses.

In sum, live learning tasks were best for students described as high in mathematical ability but low in prior physics knowledge; or as ascendant, assertive, self-assured, active, and independent; or as flighty, irresponsible, and unable to stick to tasks that do not interest them; or as unlikely to seek film learning experience on their own. Film learning tasks were best for students described as low in mathematical ability but high in prior physics knowledge; or as passive observers lacking in self confidence; or as responsible and conscientious; or as likely to seek film learning experience on their own.

Now, this study was strong in important respects: It used a substantial amount of real instruction, treatments were clearly defined, measures were of good quality, and the student sample was large. But the methodological criticism is obvious (at least it is today)—aptitude complexes should have been studied by considering all the individual variables jointly. There might well be moderating relations among PK, QK, CR, and EA aptitudes. There should also be patterns of relations among these variables that define profiles or categories of persons well served by one or another treatment. These are defined in a multivariate aptitude space, but they are categories of whole persons, not lists of interacting variables. Furthermore, in hindsight, a much deeper interpretation might have been gained. If I were doing this research today, I would next interview successful and unsuccessful students from these groups about their learning activities and collect think-aloud protocols of their work on the physics problems to reach a richer description of psychological processes in each kind of person–situation combination.[2]

Thus, ATI experiments can be used to dissect functionally different aspects of aptitude operating jointly in learning from instruction as well as functionally different aspects of the instructional situation. But they need to be aimed at understanding the kinds of persons (as aptitude complexes or profiles) that are served well or poorly by an instructional treatment, not merely at discovering the list of individual variables that interact. Also, one need not think of using this result only as a decision rule for assigning students to different treatments. One could also use it to redesign either treatment or to make a combined treatment with the aim of eliminating ATI, as Bunderson (1969) argued long ago. Either way, the result is both practically and theoretically useful.

BUILDING A FRAMEWORK FOR APTITUDE THEORIES

Let us move back now to consider in the abstract what aptitude theories are today and should be tomorrow. The question is, What kind of framework for aptitude theories should we construct and pursue?

The Place of Aptitude Theory in Psychology

Aptitude theory should be thought of as a linking science, aimed at descriptive and explanatory concepts that connect the characteristics and capabilities of persons to features of treatment environments, real or

[2]There are important connections to be built between ATI research and the methods used in cognitive analyses of expert and novice performance. Experiments with task conditions chosen to characterize expert–novice performance differences are formally equivalent to within-person ATI designs; the expert–novice contrast is the aptitude variable. Unfortunately, little work that integrates the two approaches has yet been done.

desired, so as to reach goals of field achievement. Any purposefully designed instructional program, therapy, or person–machine system is implicitly a theory of how a goal can be reached given existing or expected conditions, both personal and environmental. The usage here is akin to Simon's (1969) vision of design science as a link between abstract general principles and the achievement of real-world goals. However, in psychology to date and particularly in instructional psychology, most attempts to forge such links have been built on the strong simplifying assumption that individual differences could be ignored. Research on aptitude can thus be only loosely sketched into Simon's picture of an instructional design science. The connection of aptitude constructs to constructs of field achievements has been largely empirical and atheoretical. The connection with treatment design has been virtually nonexistent. Still today, most instructional designs, including intelligent tutors, routinely assume that learners come in as blank slates or that they are relatively uniform in ability and prior knowledge. The connection of aptitude constructs to general psychological theory has also remained vague and unanalyzed, for the most part.

But aptitude theories could be aimed at linking differential constructs into learning, achievement, and instructional design theories (Snow, 1991b). As already argued, they could also be particularized to the important field achievements and treatment designs of concern in a specific situation.

Constituents of an Aptitude Theory

What are the constituents of an aptitude theory in such a situation? Some general features of such a theory are listed in Table 2, even though we do

TABLE 2
Constituents of an Aptitude Theory

1. Convergent and discriminant validity
2. Predictive validity
3. Differential validity
4. Process explanation
5. Other boundary conditions
6. Short-term malleability
7. Long-term development
8. Measurement model
9. Methodological model
10. Selection decision rules
11. Classification decision rules
12. Education decision rules

not yet have any theories in this full form today. Here I identify these points briefly in order to devote the remainder of this article to Point 4 in Table 2, which I think is the most important for theory-oriented aptitude research today and tomorrow.

Points 1 and 2 are obvious. Any aptitude theory must include convergent and discriminant validation of its constructs and measures. To be considered aptitude, there must also be evidence of prediction to some valued criterion. Yesterday's aptitude research pretty much stopped with these first points.

Point 3 adds differential validation with respect to varying situations; this is the basic ATI view. Because the concept of aptitude always implies prediction, it always implies some particular educational (or job or therapeutic) treatment situation wherein persons will function. Describing the situation is thus part of defining the aptitude. Unless the aptitude in question is truly general, there must be situations in which that aptitude is less propaedeutic to success or not propaedeutic at all. Thorough differential validation research is required to set substantive boundary conditions on the aptitude construct.

Point 4 is process description of the person–situation interface. Describing an ATI pattern as an aptitude complex for learning from discovery-oriented or direct instruction in introductory physics is a step in the right direction. But person and situation description has to be carried to much further detail to reach a process explanation of the propaedeutic relations involved.

Point 5 concerns the need to identify other boundary conditions beyond those explicit in the primary ATI demonstration of Point 3. There will be boundaries on the ranges of aptitude variables and other person characteristics in the populations of interest. Also to be considered are boundaries around the school and community contexts within which the research is situated. All of the limits that make a particular aptitude theory a local theory (Snow, 1977a) need to be spelled out eventually, although many will not be investigated empirically.

Points 6 and 7 address the malleability and development issues. Determining the extent to which the aptitude differences in question can be changed by direct intervention, and the nature of that intervention, adds to the interpretation of the aptitude construct. Tracking the natural courses of aptitude development and differentiation across a relevant span of years similarly contributes meaning.

Points 8 and 9 justify the choices of measurement and methodological models that have gone into the development of an aptitude theory. There are alternative choices to be entertained, which might appreciably change the form of the theory or continuing research on it.

Beyond these descriptive constituents of an aptitude theory, one would expect one or more prescriptive constituents eventually. Points 10–12 thus suggest the development of decision rules for using the aptitude theory in practical selection, classification, or education systems.

REINTERPRETING APTITUDES AS INTERACTIONAL PROCESSES

The Need for New Language

Let us return now to Point 4—the process description of the person-situation interface. This is the step on which today's aptitude research has been stumbling. Although there has been progress in several directions (Snow, 1989a; Snow & Lohman, 1984; Tobias, 1989), there also has emerged a conceptual problem that I believe limits theoretical advance in psychology in general, not just in aptitude research. Simply put, the conceptual limitation derives from our tendency to think of persons and situations as independent variables, rather than as persons-in-situations as integrated systems. To build the aptitude theories of tomorrow, we need a language for describing the interactional processes that connect persons and situations—the processes that operate in their interface. Put another way, we need a language for aptitude constructs that is common to concepts of individual differences in learning, achievements from learning, and instructional treatment designs, locating aptitude in the nexus between them.

It is noteworthy that general cognitive psychology has come to recognize a similar problem. The implication from an increasing number of cognitive, developmental, cross-cultural, and anthropological studies is that situational specificity is an important feature of cognitive skill. To cite just one early collection of these views, Rogoff (1984) noted that

> Cognitive skills seem to fluctuate as a function of the situation, which suggests that skills are limited in their generality. . . .
>
> Thinking is intricately interwoven with the context of the problem to be solved. The context includes the problem's physical and conceptual structure as well as the purpose of the activity and the social milieu in which it is embedded. . . .
>
> One must attend to the content and the context of intellectual activity in order to understand thought processes. This is the case for any situation in which thinking is studied, including the laboratory context, which is not context-free as researchers frequently assume. (pp. 1–3)

Thus, in the line of research that has developed from this view, thinking skills reside in the person–situation interaction, not solely in the mind of the person. This is a radical departure for general cognitive theory; it seems to be pushed by these context- and culture-sensitive studies toward the same conception of cognitive skill that comes from the push of ATI research. The aim appears to be the same: to create a new conceptual language for theories of person–situation interactions. However, the problem for aptitude theory is even more difficult because the language we build must cover conative and affective as well as cognitive interactional processes, and individual differences in them besides.

There is a candidate theoretical language to propose for tomorrow's aptitude research, although today it may appear to be a patchwork of several different languages. That is reasonable enough in the interim, if different languages have particular strengths for different parts of the problem. The goal for tomorrow's theory, then, will be to replace today's quilt with seamless fabric.

Specifically, the proposed language uses some of Gibson's (1966, 1979) theory of affordances in perception and some of Simon's (1969) science of the artificial in treatment design, as well as language from cognitive information-processing research on comprehension (Kintsch, 1988) and reasoning (Sternberg, 1977, 1985). But I also reach back to Thorndike's (1921) connectionism and its use by Thomson (1919, 1939) to formulate a response sampling account of cognitive task intercorrelations; the modern version of this comes through Humphreys (1979, 1981). Perhaps it even reaches ahead to the new connectionism of Rumelhart, McClelland, and the PDP Research Group (1986). There are connections as well to current thinking about situated learning and distributed intelligence (Greeno, 1988; Pea, 1990; Perkins, 1990; Salomon, 1990) and also to certain aspects of modern work on phenomenological perspectives (Marton, 1983), personality theory (Hettema, 1979, 1989; Mischel, 1984), and ability factor theory (Carroll, 1989; Gustafsson, 1984, 1989). There are also substantial methodological implications (see Snow, 1991b).

There is no space here to explicate all of these views separately or to detail the interconnections that led me to cite these sources in particular.[3] Rather, to reach a concise summary, it is easiest to trace the development of this view in our Stanford Aptitude Research Project, starting in 1975.

Strategic Assembly and Control Processes

My colleagues and I (for a list of project participants, see Snow, 1989a) had accumulated by the mid-1970s many ATI results that cried out for detailed analysis. We thus began information-processing studies of key aptitude differences, hoping to reach deeper interpretations. We concentrated on

[3]This is one subject of a book in preparation entitled *Aptitude Theory*.

cognitive differences despite important ATI results on personality because it seemed the simplest way to start. However, we emphasized some hypotheses and goals that differed from those pursued by other cognitive investigators, in part to leave room for these other processes, and we have tried to bring conation and affect explicitly into the picture in the last 5 years.

First, we expected that the most important individual differences in cognitive task performance in relation to learning would show up in within-person as well as between-person strategic differences in information processing. In other words, there might be individual differences in elementary processes, as Hunt (1980) suggested, or in the performance components identified by Sternberg (1985). Persons might also differ in the sequence in which they executed component steps or in the kinds of component steps they included—we labeled these *sequence and route differences*. But most important, we thought, would be a person's facility in assembling component sequences and routes into a strategy for task performance and in reassembling or adapting this assembly as task performance proceeded. Intraindividual differences in these functions would show adaptation (i.e., learning) within cognitive performance tasks (e.g., ability tests) that should be the key to understanding similar differences in learning tasks. We labeled these adaptive functions *assembly and control processes* (for details, see Snow, 1978, 1981; Snow & Lohman, 1984). Our results from eye movement analyses as well as Sternberg-style componential analyses seemed to bear out the promise of this view. In short, our continuing hypothesis is that aptitude differences in learning appear in the person–task interface as differences in within-person adaptation to the stream of continuing changes in within-task demands and opportunities. Learners construct their performances in instructional situations by drawing on their resources and assembling, reassembling, and controlling them to adapt to perceived needs and opportunities in the situation. We also think there are thresholds of task novelty and complexity for each person–task interface near which learning is optimal and flexible assembly and control functions are most needed. No single information-processing model can account for performance near this threshold, even if such models are adequate to characterize the automatic performance observed when persons are working far below their thresholds.

Second, our goal was to integrate an information-processing account of individual differences in aptitude for learning with the correlational evidence amassed over this century in factor analytic study of cognitive ability organization. Most of the other investigators were studying one ability at a time. We produced multidimensional scalings of old ability matrices as well as our own new ones because we wanted to represent the multivariate interrelations among ability tests in a way that provided a more direct map of cognitive interrelations and yet was also consistent with the old factor analytic results (see Snow, Kyllonen, & Marshalek, 1984). With this sort of map in hand we could study the degree to which information-processing models of single tasks could be stitched into continua of tasks in the multivariate space. After all, an information-processing theory of particular abilities has to depict the similarities and differences between tasks, just as the correlations between tests do. An information-processing theory of cognitive abilities has to be consistent with the correlational structure of ability tests in general. This would also be true for a theory of personality differences in learning, and we are currently at work on similar multivariate maps in this domain.

At least for cognitive abilities, we believe we succeeded in demonstrating that a Radex structure provides a fitting and useful map (see Snow et al., 1984). It distinguishes the more complex and general ability constructs in the center of the Radex from the simpler, more specialized and domain-specific abilities distributed around the periphery and suggests that the arrays of the Radex represent continua of increasing information-processing complexity as one moves from periphery to center. The central ability constructs show much stronger correlations with learning from instruction, and more potent and reliable ATI results, than do the peripheral abilities. Information-processing analyses also suggest that they involve more variance due to adaptive, strategic assembly, and control processes. In other words, cognitive aptitude differences in the center of the Radex are differences in within-task flexible adaptation of processing, at least in significant part.

A Sampling-Assembly-Control Model of Person-situation Interaction

Putting these views and results together with evidence from many other investigators as it accumulated, we reached a way of describing both intraindividual adaptation and interindividual differences, both within and across situations, that seemed flexible enough to capture the dynamics of processing in person-situation interactions. An early version was called simply *a response sampling model* to honor the Thorndike-Thomson origin, although the whole is better described as a *sampling-assembly-control model,* and the sampling is assumed to be bidirectional (see Snow & Lohman, 1984).

The basic event at the interface of person and situation is a sampling, of person by situation and situation by person, governed by associative networks of stimulus and response components residing in the inner environment of the person and the outer environment of the situation.

Although based on associative networks of components, the model is by no means limited to a stimulus–response association theory. Rather, the associative network provides the base from which a variety of structures and representations can be assembled as needed in a particular person–situation match. The neutral term *component* is used to cover stimulus–response bonds but also other kinds of hypothesized mental units or connections, including information-processing components, plans, images, learning sets, schemata, nodes in semantic networks, productions in production systems, and the like. The model is thus not restricted to any one cognitive representational construct and accommodates nonrepresentational constructs as well. Furthermore, although components are conveniently described in the model as bits and pieces of knowledge (and skill), the term *component* can apply as well to key aspects of conative and affective aptitudes.

First consider the inner environment of the person. Each individual's inner environment contains a vast assortment of response components. They are probabilistically interconnected in multiple associative networks; that is, the connections vary in strength to reflect the person's learning history. Many sorts of assemblies of these components can be constructed in different ways for different situations. These assemblies are also decomposable, so parts can be used in other assemblies as needed. The products of past learning are components already assembled into units to be triggered anew by situations similar to those previously faced. The products of continuing learning are additional components, new assemblies of both new and old components, and strengthened connections between them. But learning also exercises and thus strengthens the assembly and control functions themselves. In short, the human mental system is designed to be loosely coupled and flexible in assembling and reassembling components into performance programs to meet varying situational needs. Because it reflects personal learning history in this regard, it is also highly idiosyncratic.

Now consider the person–situation interface. Each performance situation samples from each person, in the sense that the demands and opportunities it presents draw forth whatever relevant response components and assemblies of components each person can muster. But the person also samples the situation, in the sense that stimulus components are perceived and selected. Stimulus components may suggest a demand for particular response components or assemblies. They may also provide an opportunity to use particular response components or assemblies. And the situation may contribute components to the performance that the person then need not provide. Of course, each person's learning history will influence this perception–selection process to some degree. Thus, the sampling is designed in part by the demands and opportunities afforded by the performance situation presented and in part by the possibilities and constraints afforded by the assembly and control history of the performing person.

Considering the person's learning history suggests some further distinctions between several kinds of situational demands and opportunities. There are those involving the retrieval and application of old, familiar component assemblies versus those involving the construction and application of novel component assemblies. Also, there are those that call forth familiar or novel performance assemblies from the learner versus those that supplant the need for such performance assemblies, by providing stimulus components as prosthetics that can substitute for response components. Complex tasks will typically involve some of each kind of component and will further require the flexible reassembly of interconnections within and between them as various parts of the learning task proceed. But all these situational components are there to be perceived and used as such, at least for persons who are tuned to do so.

Thus, situations can be described as consisting of networks of stimulus components that (a) represent either demands for or opportunities to use particular response components or assemblies, but (b) may also supplant the need for particular response components or assemblies, and (c) may be either familiar or novel with respect to the person's learning history. Note that these essential aspects of situations are defined by their connections with aspects of person performance, just as the essential features of person performance were defined earlier by their connections to situations. We can now simplify the language, and bring out some other implications, by recognizing that all these person-situation connections are *affordances* in Gibson's (1966, 1979) sense of that term and also *artifacts* in Simon's (1969) sense of that term.

Affordances, Artifacts, and Aptitude Differences

Gibson's concept of affordances addresses the mutuality of person and situation in the control of perception-action sequences. To paraphrase Gibson (1979, pp. 127–129, 138–139), the affordances of a situation are what it offers the person, what it provides or furnishes, for good or ill. The term implies a complementarity of person and situation, as in an ecological niche. A niche is a place or setting that is appropriate for a person—a combination of situational components into which the person "fits." Likewise, a situation is an assembly of affordances with respect to some particular person or kind of person. Affordances reflect the invitation, demand, or opportunity structure of a situation for those persons who are tuned or prepared to perceive it. Particular affordances invite particular actions. Gibson's concept of affordances is thus at many points close to the old meanings and roots of aptitude previously noted: Milton's (1643) "sociable and helpful aptitude between man and woman" becomes Gibson's (1979) "what the male affords the female is reciprocal to what the female affords the male" (p. 135).

This implication of aptitude in Gibson's theory has also been elaborated by others in the movement now called ecological realism.

> To say that affordances are perceived means that information specifying the affordances is available in the stimulation and can be detected by a properly attuned perceptual system. To detect affordance is, quite simply, to detect meaning.
>
> Different animals engage in very different behaviors. The potential purposive behaviors are called its *effectivities*. . . . Whether an animal flies, swims, walks, or slithers; whether it pecks, nibbles, sucks, or licks; whether it smokes, watches television, or mugs old people will "determine" the affordances it can detect. Because information specifies *behaviors* that are afforded and because different animals have different sets of effectivities, *affordances belong to animal-environment systems and nothing less.* [Thus] information about affordances is "personal"; it is unique to particular animal-environment units. (Michaels & Carello, 1981, pp. 42–43)

Translating this view of ecological realism into ATI terms, research on aptitude requires a detailed analysis of the affordance–effectivity matches of different learners and different instructional treatments. This analysis would emphasize the opportunities offered by a particular treatment to be detected and capitalized on by a particular person to achieve a goal. The analysis also would remain at a level that identifies the unique person–situation synergy in local ecological terms, rather than reducing to physical or biological description or abstracting to generalized principles. Because ecological information is personal, it is unique to particular person–situation units. There is therefore no detached or abstracted list of qualities of instructional treatments that will be equally important for all persons or similar list of qualities of persons that will be equally important for all treatments. Aptitude is the unique coalition of affordances and effectivities in particular person–treatment systems.

The analysis of aptitudes as affordances emphasizes the important ways in which person and situation are tuned to one another to be in harmony for successful performance. An equally important question for aptitude theory is the analysis of inaptitudes, that is, the disharmonies in the person–situation interface that result in failure. Some aspects of these disharmonies can be described as failures of tuning to perceive affordances. Other aspects seem better described in Simon's language of artifacts and interface redesign.

To paraphrase Simon (1969, pp. 7–13), artifacts are interfaces between inner and outer environments. If these inner and outer environments are appropriate to one another (i.e., they are adapted or designed to fit one another optimally), then the artifact serves its purpose essentially unnoticed. Often, however, interface design can be only approximate. Then the limiting properties of the inner system will appear in the failure to match the demands of the taxing outer environment.

For a particular person in a particular environment, the empirical evidence of aptitude arises from the inabilities of the behavioral system to adapt perfectly to its environment. Aptitude differences between persons in particular environments show through at the interface as a presence–absence (or degree) of these inabilities. For a person who is perfectly suited to a treatment or a treatment that is perfectly suited to a person, the goal is reached successfully. The presence of aptitude is inferred from this success, but it is attributable to both person and environment, that is, to their benign interface. For a person who is not perfectly adapted to a treatment or a treatment that is not perfectly adapted to a person, the goal is not successfully reached. This failure shows that inaptitude of some kind is present. But again, inaptitude is attributable to the interface: Either the inner system or the outer system, or both, need to be redesigned to bring them into adaptive harmony. Research aimed at system redesign needs to find the key inabilities in the interface that constitute the mismatch and correct them. System redesign proceeds by reshaping the treatment to eliminate demands, thereby circumventing limitations, or by removing limitations directly by retraining the person.

SOME SUMMARY IMPLICATIONS FOR THE APTITUDE THEORIES OF TOMORROW

In conclusion, at least the main implications for the aptitude theories of tomorrow can be summed up as follows:

1. Aptitudes are affordances (Gibson, 1966, 1979). They are properties of the union of person and environment that exhibit the opportunity structure of a situation and the effectivity structure of the person in fitting that situation, that is, in taking advantage of the opportunities afforded for learning. Particular persons are tuned or prepared to perceive particular affordances in a situation that invite the particular actions they are able to assemble.

2. Inaptitudes are also artifacts (Simon, 1969). An aptitude is an interface between an inner environment (the person) and an outer environment (the instructional treatment situation). Aptitude differences are

invisible when inner and outer environments are perfectly adapted to one another. When the outer environment is demanding, however, limiting properties of the inner environment show through at the interface as aptitude differences. Instructional treatment redesign seeks to circumvent these inner limiting properties (inaptitudes) by adapting the outer environment or by changing the inner environment (removing the inaptitudes by direct training).

3. From the view of Simon's (1969) artifact design, future research on aptitude requires a detailed analysis of the treatment design features that seem mismatched to the person when limiting properties of the person show through in the performance interface. The analysis is geared to detect inaptitudes (weaknesses) so as to remove or circumvent them in treatment redesign. From the view of Gibson's (1966, 1979) affordance theory, future research on aptitude requires a detailed analysis of the affordance–effectivity matches in different person–treatment unions. The analysis is geared to detect aptitudes (strengths) so as to capitalize on them in treatment redesign. The two views are complementary because the most successful instructional treatments will be those that both capitalize on strengths and compensate for weaknesses, for each individual to be treated.

4. Aptitude is situated. It is reflected in the tuning of particular persons to the particular demands and opportunities of a situation. It therefore resides in the union of person in situation, not in the mind alone. It is a two-way sampling of performance components and their assembly between person and situation and is thus also distributed between person and situation; the situation contains some pieces of what the person needs or can use to accomplish a given task. But individuals need to be tuned to perceive and use those pieces and need also to supply some pieces from their own learning history. Some individuals are prepared to perceive these affordances—to use the pieces provided by the situation—but others are not. Among those who are so tuned, each may supply slightly different pieces, although each piece thus supplied may be equally effective. The result is that some persons succeed in learning in a given situation; they are in harmony with it. Others do not, because they are not tuned to use what the situation affords or to produce what it demands. The tuning is at once cognitive, conative, and affective; learners who are not tuned in will tune out, and ultimately turn off.

5. Persons assemble their performances in response to these perceived affordances from vast banks of potential response components organized into associative networks. As a function of learning history, parts of these networks may be coupled tightly and triggered as units; others may be coupled loosely and disconnected easily when parts are triggered. Actually, each component might itself be thought of as a network, also coupled either tightly or loosely. Continuing this reduction might eventually reach the

neural networks of new connectionism. But that would go beyond the ken here.

6. Persons also control or adapt these component assemblies as affordances change in a dynamic situation. In a heterogeneous group of persons, some components and assemblies will be held in common and some will not. The connections among components will differ in strength. The assembly and control history of these components and assemblies will also differ from person to person and therefore so will their facility for adaptive assembly and control during performance in a present situation.

7. In this view, valid aptitude measures (whether maximum performance tasks or typical response tasks) are situations that evoke some semblance of the sample of components and assemblies and their adaptations that are also evoked by some learning or achievement task to which the aptitude measures are therefore correlated. The test situation and the criterion situation involve affordances that are invariant across these situations; that is, the samples drawn by the two situations overlap substantially. The size of the correlation suggests how large is the overlap.

8. Aptitude–treatment interaction occurs because the affordance profiles of person–situation interfaces differ. To continue the earlier example, a relatively incomplete and unstructured situation samples just the kinds of assemblies that persons described as able, independent, mastery oriented, flexible, and the like are tuned to produce. Highly structured and complete instruction does not provide that opportunity for them. It does, however, provide some of the assemblies that less able, less independent, less mastery-oriented learners cannot provide for themselves, and it does not sample what such learners cannot produce.

9. The three major cognitive aptitude constructs can be distinguished in this assembly and control process. Fluid intelligence reflects the more flexible assembly and adaptation of strategies for performance in novel unfamiliar tasks. Crystallized intelligence reflects more the retrieval and adaptation of old assemblies for familiar tasks. Visualization ability reflects a collection of specialized skills that pop in and out of relevance in a variety of tasks that afford their use; other special abilities can be similarly described.

10. Finally, one can think of a performance assembly pathway, from activation in and retrieval from the person's bank of experience, to adaptation in the person–situation interface, to action in the task or instructional situation. Performance is assembled and reassembled along this path to meet the characteristic affordance profile of this situation. An analysis of this profile with respect to familiarity–novelty, structure completeness, and the use of special knowledge and skills will provide a picture of its cognitive aptitude requirements and opportunities for each person. However, each person's mental bank contains not only bits and pieces of

knowledge and skill, but also wishes, wants, needs, intentions, interests, attitudes, etc. These are also component networks that may differ in strength and that can be triggered in whole or in part by situational affordances. In parallel with the performance assembly pathway, one can think of a performance commitment pathway, from activation to action, that accounts for the appearance of conative and affective aptitude differences. The operation of such aptitude constructs as achievement motivation, anxiety, mastery versus performance orientation, conformity–responsibility, independence–flexibility, and extraversion–ascendancy may also be describable in terms of the assembly and control of sampling processes and the tuning of these processes to affordances in the person–situation interface (see Snow, 1989b). The job for tomorrow's aptitude theorists will be to convert each of these constructs, along with the cognitive constructs, into more detailed affordance sampling descriptions in the treatment situations with which they have been associated in ATI research.

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