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Dual Coding Theory and Education

James M. Clark[1,3] and Allan Paivio[2]

Dual coding theory (DCT) explains human behavior and experience in terms of dynamic associative processes that operate on a rich network of modality-specific verbal and nonverbal (or imagery) representations. We first describe the underlying premises of the theory and then show how the basic DCT mechanisms can be used to model diverse educational phenomena. The research demonstrates that concreteness, imagery, and verbal associative processes play major roles in various educational domains: the representation and comprehension of knowledge, learning and memory of school material, effective instruction, individual differences, achievement motivation and test anxiety, and the learning of motor skills. DCT also has important implications for the science and practice of educational psychology — specifically, for educational research and teacher education. We show not only that DCT provides a unified explanation for diverse topics in education, but also that its mechanistic framework accommodates theories cast in terms of strategies and other high-level psychological processes. Although much additional research needs to be done, the concrete models that DCT offers for the behavior and experience of students, teachers, and educational psychologists further our understanding of educational phenomena and strengthen related pedagogical practices.

KEY WORDS: imagery; verbal processes; unified educational theory.

INTRODUCTION

Both the science and practice of education depend on a firm understanding of many psychological phenomena, including such cognitive topics

[1]Department of Psychology, University of Winnipeg, Winnipeg, Manitoba, Canada R3B 2E9.
[2]Department of Psychology, University of Western Ontario, London, Ontario, Canada N6A 5C2.
[3]To whom all correspondence should be addressed.

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as the structure of knowledge, study skills, student aptitudes, and effective instructional practices. Less cognitive psychological topics, such as affect (e.g., student interests and motivation, evaluation anxiety) and perceptual-motor processes (e.g., handwriting, typing) are also relevant to education. The range of these phenomena challenges teachers, educational researchers, and psychologists to develop general psychological theories that can explain diverse facets of human behavior and experience.

One way to achieve such unified theories is by reductionist approaches that identify molecular psychological mechanisms underlying domain-specific molar explanations for educational and related cognitive phenomena. By molar explanations, we mean strategies, beliefs, and other high-level psychological processes. For example, a domain-specific molar explanation for effective study skills might describe note-taking, elaboration, and other learning strategies, as well as the metacognitive processes that control their use. A domain-specific molar explanation for effective instruction might describe the use of concrete examples, lesson summaries, and other teaching methods, along with the executive processes involved in the selection and implementation of those methods. A reductionist would try to unify the distinct domains of study skills and effective teaching by considering shared mechanisms that underlie the somewhat different molar theories. Both the elaboration of text by students and the use of concrete examples by teachers, for example, may increase the likelihood that visual images are evoked by the to-be-learned material, and this shared imagery mechanism could contribute to the effects on comprehension and memory of both elaboration and examples. Similarly, the metacognitive processes of students and teachers involve shared verbal mechanisms by which self-talk guides and controls behavior (e.g., "Think of an example"; "Give students a summary"), although the specific contents of the statements vary.

The present paper describes one theory of basic psychological mechanisms that permits unified explanations for diverse educational phenomena. Dual Coding Theory (DCT) (Paivio, 1971, 1986) is an empirically well-founded characterization of the mental processes that underlie human behavior and experience. DCT explains psychological phenomena by the collective action of nonverbal and verbal mental systems that are specialized for the processing of imagery and linguistic information, respectively. DCT theoretical mechanisms and associated empirical phenomena are relevant to various aspects of human cognition, as well as emotion, motor skills, and other psychological domains. This breadth suggests that the theory could provide a useful foundation for a general psychological model of education and could strengthen current efforts to explain educational phenomena in terms of cognitive mechanisms (e.g., Dillon and Sternberg, 1986;

Gagne, 1985; Mayer, 1987). We first describe the theory and then show how DCT mechanisms can help to integrate the extensive research literature on education.

DUAL CODING THEORY

The underlying assumptions of DCT concern basic mental structures and processes: the structures are associative networks of verbal and imaginal representations, and the processes concern the development and activation of those structures, including the effects of context on the spread of activation among representations. These DCT assumptions are presented more fully in many articles and books that describe the overall theory (Paivio, 1971, 1986) and its application to language (e.g., Paivio and Begg, 1981), memory (e.g., Clark and Paivio, 1987), and other psychological topics.

Imagery and Verbal Mental Representations

According to DCT, mental representations are associated with theoretically distinct verbal and nonverbal symbolic modes and retain properties of the concrete sensorimotor events on which they are based (see Fig. 1). The verbal system contains visual, auditory, articulatory, and other modality-specific verbal codes (e.g., representations for such words as book, text, livre, school, teacher, learn, strategy, mathematics, and worry). These word-like codes are arbitrary symbols that denote concrete objects and events, as well as abstract ideas. For example, the English words "book" and "text" and the French word "livre" are arbitrary verbal labels for the same object. Verbal codes retain their separate and discrete identities even when connected in hierarchies or other associative networks. That is, a word such as "livre" can be associatively connected to its English translation "book" and included in the sentence "Livre is the French translation for book," but the words remain separate entities. Moreover, verbal representations are generally processed in a serial or sequential manner. Thinking of the sentence "Livre is the French translation for book," for example, means attending successively to the words. A verbal description of some classroom scene or event similarly involves a sequential description.

Nonverbal representations include modality-specific images for shapes (e.g., a chemical model), environmental sounds (e.g., school bell), actions (e.g., drawing lines or pressing keys), skeletal or visceral sensations related to emotion (e.g., clenched jaw, racing heart), and other nonlinguistic objects

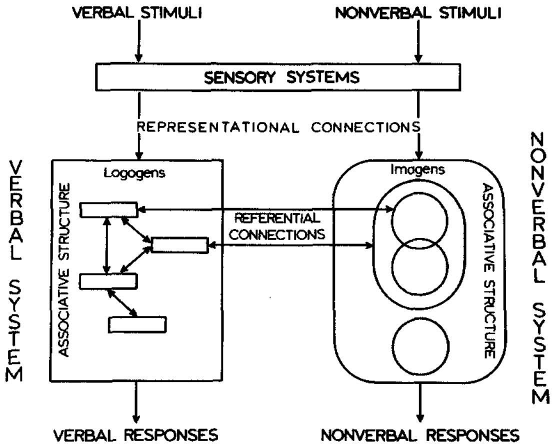

Fig. 1. Verbal and nonverbal symbolic systems of Dual Coding Theory. From *Mental Representations: A Dual Coding Approach* by A. Paivio (1986). Reprinted by permission. This figure shows the representational units and their referential (between-system) and associative (within-system) interconnections.

and events. Such imaginal representations are analogous or perceptually similar to the events that they denote, rather than being arbitrary symbols. That is, mental images for "book" have visual, tactual, and other perceptual qualities similar to those evoked by the referent objects on which the images are based. Similarly, mental images evoked by emotionally laden words or phrases (e.g., "I like my teacher" or "I hate math") have visceral properties similar to those experienced when one is actually in the presence of the affective object. In contrast to verbal processing, which is sequential, nonverbal representations can encode information in parallel or simultaneously. A single mental image of a complex classroom or playground scene, for example, contains much detailed information; stated colloquially, "pictures are worth a thousand words," and so are mental images. Because complex images can integrate the parts of events, objects may "lose" their separate identities and become spatially embedded or nested in the whole imaginal structure. For example, the distinct shape of a triangle might "fade" as imagined lines are added for a proof in geometry. Mental images are also amenable to dynamic spatial transformations that are not possible with verbal representations. That is, students can visualize the rotation of a chemical model, the effect of tilting a container of liquid, an explorer's ship circumnavigating the globe, or other spatial transformations, but analogous operations are not possible within the verbal system.

DCT's other structural assumptions concern the connections that link verbal and nonverbal representations into a complex associative network (see Fig. 1). Links between the two systems are called referential connections. They join corresponding verbal and imaginal codes and potentially allow such operations as imaging to words and naming to pictures. For example, the word "school" might evoke negative visual images and unpleasant visceral sensations in children who have formed links between the word and these nonverbal reactions. Similarly, the word "Canada" spoken in a geography class might arouse a clear visual image of the country's outline, or the word "Principal" might elicit various images in teachers and students. Referential connections in the opposite direction, from image to name, permit students to label pieces of science apparatus (e.g., test tube, bunsen burner), biological objects and their parts (e.g., praying mantis, nucleus), the states on a map of the U.S., and other figural information.

A second kind of link, called associative connections in DCT, joins representations within the verbal and nonverbal systems. On the verbal side, words are joined to other related words. In the case of a student who has an aversion to school, the word "school" might elicit such verbal associations as "hate," "boring," or "afraid." Additional examples of verbal associations include: connections between instance and category names (e.g., "gold," "lead," "iron," and other instance names acquiring links to the term "metal"), teachers and students encoding a lesson as an associative chain of key terms and phrases, or the schematic representation for a lab report as a linked series of labeled parts (e.g., introduction, method, results, discussion).

Within the nonverbal system, associative connections join images to other images in either the same or different sensory modalities. To continue with the school aversion example, sight of school might evoke visual images and nonverbal visceral responses reminiscent of unpleasant school experiences. Similarly, a visual image of a bunsen burner can be associated with visual images for other objects in a science experiment, with auditory and olfactory images for the sound and smell of gas, and with motor images for adjusting the flow of gas. Students also link successive images for concrete events reported in novels, history and geography texts, and other concrete school materials.

Processing Assumptions

The development and activation of verbal and imaginal associative structures are governed by DCT's processing assumptions. A basic premise is that individual verbal and imaginal representations vary in their activity levels, with some representations highly active and others depressed at any given time. Strong activity may be associated with conscious nonverbal and verbal experiences (e.g., an image of a classroom, or thinking of such words as "lazy" or "intelligent"), although arousal of codes does not always lead to conscious experiences. Active mental representations can in turn activate associatively related nodes in the network, and this spreading activation results in complex patterns of arousal among the representations in the network. Metaphorically, one can think of human cognition as a constantly changing landscape with elevated areas (peaks) indicating aroused mental codes and low-lying areas (valleys) indicating depressed codes. The particular shape of the landscape depends on complex and subtle associative mechanisms.

As a hypothetical example of this spreading activation, consider how sight of a particular student would increase the activity in stored images of the student, and how activation may then spread from those images to other verbal and nonverbal nodes in the network. If the teacher's image of a student is associated with the mental code for the word "lazy," then activation of that label would in turn arouse a repertoire of associated images and verbal representations. Nonverbal associates of "lazy" could include visual or kinesthetic images of patting the child on the back, frowning, or turning away from the student, as well as codes for sympathetic or aversive visceral sensations and other mental images. Verbal associations activated by "lazy" and the image of the boy might include such covert statements as "Homework probably not done," "Needs praise," "What can I do?" or "Just like his brother!" In this manner, spreading activation results in complex patterns of arousal in the network, with each pattern in turn determining succeeding responses of the mental system.

With respect to the development of mental representations and their interconnections, DCT emphasizes the central role of past experience. The word "Scud," for example, had little semantic, visual, or affective meaning for most people until recent events in the Middle East. One way in which the importance of experience reveals itself is through idiosyncratic and context-dependent reactions to environmental events. Although similar experiences promote common mental structures, variability in individual experiences means that mental representations and their interconnections can vary from person to person, depending upon people's specific history with the elements in the network.

Even given common experiences, the development of connections will vary with the accessibility of existing codes; for example, poor student performance may tend to be labeled "laziness" by one teacher and "boredom" by another. General predispositions to respond in certain ways are captured in DCT and other associative theories by differences in the amount of stimulation required to activate labels in the mental network. In our example, the net effect of idiosyncratic experiences and dispositional factors would be that some teachers would acquire strong referential connections between their images for a student and the mental word "lazy," whereas others would associate alternative labels (e.g., "bored" or "slow") or would lack labels because of inadequate experiences, explicit suppression of evaluative terms, or other factors.

In addition to the strengths of existing representations and their connections, the pattern of activation on any particular occasion is determined in part by instructions and other moderating contextual influences that temporarily enhance activation of some connections and inhibit others. For example, presenting pictures or telling students to generate images for pairs of words will prime the imagery system and increase the likelihood that words will activate mental images. Pictures and instructions to image indeed do increase reports of imagery in various tasks and produce other effects consistent with an imagery interpretation (see later discussion).

According to DCT, the relative activation of the nonverbal system is particularly important for understanding human behavior because the imagery system has unique theoretical and empirical properties. We noted earlier, for example, that the imagery system can unify multiple objects into an integrated image, and we will see later that such integration can in turn facilitate memory for textbook and other school material. The probability of imagery processing depends on several classes of variables (Paivio, 1971, 1986), and all have direct educational implications. We have already stated that instructions and related context effects can influence the arousal of imagery, so that students and others are more likely to generate mental images if instructed to do so than if left to their own devices. Such imagery instructions are incorporated into various memory techniques that facilitate vocabulary and other school learning.

A second important determinant of imagery processing is the imagery value or concreteness of the material being studied. Theoretically, imagery and concreteness reflect the availability and strength of word-to-image referential connections. That is, concrete words such as book, teacher, bunsen burner, and blackboard denote tangible objects that are more likely than abstract words to have corresponding images. Abstract words such as ability, success, effort, mass, and learning-disability do not refer to concrete, tangible objects or events, and are less likely to evoke an image of specific referents. We show later that concreteness and imagery value are important attributes of educational material. A poem incorporating concrete events and figurative language, for example, will be more likely to evoke imagery in students than abstract passages.

A third factor affecting nonverbal processing is variation among people in the tendency and capacity to use imagery; that is, individual differences. Some students and teachers will use imagery easily and spontaneously under many conditions, whereas others will rarely image and only with difficulty. These individual differences in imagery abilities and habits have important consequences for education. Students who have trouble imaging, for example, may fail to remember passages of text that benefit from imaginal processing, may not understand geography or other spatial facts in a concrete way, and might do poorly at visualizing the steps in a geometric proof, spelling difficult words, or even printing letters correctly.

Instructions and related context effects influence not only the relative activation of verbal and nonverbal systems, but also the patterns of activation within the nonverbal and verbal systems. Instructions to students to generate synonyms, for example, will make such responses more likely than when students free-associate to words (Clark, 1978). Specific context effects can also operate indirectly. Wynne *et al.* (1965), for example, found that adding antonym-evoking stimuli to the beginning of a free-association list increased the frequency of antonym responses for later items. Presumably, words such as "black" and "hot," which tend to elicit opposite responses (e.g., "white," "cold"), activated the word "antonym" or some equivalent term, which then primed antonym responses for later items. In a similar way, a teacher modeling certain classes of response for various objects (e.g., superordinate names, colors, shapes) will prime that class of response for subsequent items presented to students.

There are many classroom analogues to selective priming effects. In the case of a teacher's response to a particular student, for example, the reaction "smart" to John's specific behavior may be more easily aroused if primed by some related event, and the response "Just like his brother!" might be primed by seeing the brother in the playground. Telling students to image the events in stories also operates in a selective manner to increase the likelihood that students experience mental images. Within the verbal system, asking students to classify names of animals (e.g., crocodile, rabbit) into categories primes verbal associative pathways and responses associated with superordinates (e.g., for reptile, mammal), and inhibits other associations not relevant to the task (e.g., dangerous, Dundee, long ears, bunny, Easter). These effects of context can be quite precise; whether the digits 2 and 6 activate 4, 8, 12, or 26, for example, will depend on the presence or absence of arithmetic symbols (minus, -, plus, +, times, ×).

Discussion of DCT

Multiple verbal and imaginal representations, the complex referential and associative network, the effects of history and context, and the subtle effects of spreading activation all combine to permit powerful models to be built for diverse psychological phenomena. A DCT model, in essence, consists of hypothetical networks of verbal and nonverbal representations and descriptions of the mediating patterns of activation (i.e., the states of the network) that intervene between stimulus and response events. Learning foreign vocabulary, for example, involves successive verbal and nonverbal representations that are activated during initial study of the word pairs and during later efforts to retrieve the translations. The specific ways in which verbal and nonverbal mechanisms contribute to performance will vary with the task, stimulus characteristics, past and present events, and individual differences.

Although DCT models emphasize basic mechanisms, the theory also permits and complements explanations cast in terms of such molar processes as strategies and beliefs. Deliberate determinants of teacher and student behavior, such as strategies, are sometimes contrasted with passive associative mechanisms, but the true relation between strategies and associative processes is more complementary than competitive. Ultimately, the human mind represents and processes strategies in terms of nonstrategy mechanisms, possibly in terms of associative networks of verbal and nonverbal mental representations. We return to this question in the General Discussion, but it is important to note that the appropriate questions to ask during the following analyses of educational phenomena are whether the proposed mechanisms of DCT are compatible with higher-level explanations and further our understanding of how those molar processes work, rather than whether DCT can replace existing molar theories.

The remainder of this article demonstrates that imagery, concreteness, verbal and nonverbal associative networks, and other DCT constructs can provide unified explanations for educational psychology. A central theme will be that diverse educational phenomena show the collective contribution of imagery and verbal processes to human behavior and experience. The examples considered not only draw on DCT's historical strengths in the area of human cognition (e.g., the structure of knowledge, learning and study skills, effective instruction), but also demonstrate that the theory is well-suited for less cognitive topics (e.g., emotions and motor skills). Because we discuss a broad range of educational phenomena, our coverage is highly selective, and some controversial and complex issues are mentioned just briefly.

THE STRUCTURE OF KNOWLEDGE

The primary purpose of education is to transmit knowledge; consequently, much educational and cognitive research has attempted to identify the basic psychological mechanisms by which information in texts and other educational sources is represented. A DCT account of knowledge emphasizes the contribution of both nonverbal and verbal systems, which we consider in turn.

Imagery Processes in the Meaning of Words and Text

The knowledge relevant to education is to a large extent represented verbally in books, teacher and student notes, and other forms of text. Because of referential connections between the verbal and nonverbal systems and because images have special properties, DCT maintains that the probability and ease of image arousal plays an important role in the representation of text meaning. This hypothesis is clearly supported by research on word meaning, text comprehension, and related phenomena.

DCT predicts that word concreteness and imagery value should be central variables in cognitive and educational tasks related to meaning. Empirically, concreteness and imagery value have been measured by ratings of the ease with which words, sentences, or larger units of text evoke a visual, auditory, or other mental picture (imagery value), or the degree to which they refer to tangible objects with concrete referents (concreteness) (Paivio *et al.,* 1968). Ratings of these attributes are highly reliable and correlated, and theoretically reflect differential access to nonverbal perceptual knowledge. This DCT assumption is supported by a variety of findings (see Paivio, 1971). Word concreteness and imagery value, for example, correlate negatively with the latency to generate mental images (e.g., Paivio, 1966, 1975a), and positively with the number of sensory properties that people can think of for words (Katz, 1976) and with postexperimental reports of spontaneous imagery during performance of various cognitive tasks (e.g., Bugelski, 1970; Clark and Paivio, 1989a). Such findings, and factor analyses involving other variables (e.g., Paivio, 1968), support the DCT view that concreteness and imagery values primarily reflect accessibility to visual images and other nonverbal representations. That images for concrete words can be generated as fast as simple word associations (Clark and Paivio, 1989a; Paivio, 1966) indicates that even conscious imagery occurs quickly enough to contribute to word and text comprehension.

The importance of imagery value and concreteness for the meaning and comprehension of individual words has been demonstrated in various ways, including correlations with several measures of the ease of defining words. In one study, for example, university students were tape-recorded while they orally defined concrete and abstract words equated for frequency and meaningfulness (Reynolds and Paivio, 1968). The definitions for the abstract words contained more hesitations and other speech dysfluencies (e.g., "ah" pauses) than definitions for the concrete words. In a related study, O'Neill (1972) had university students rate how easy or difficult it was to define the meaning of 277 nouns. Ease of definition correlated .70 with rated imagery value and .64 with rated concreteness, consistent with the DCT view that nonverbal processes play important roles in word meaning.

A variety of rating and association tasks relevant to meaning have shown that, relative to abstract words, concrete words more readily access superordinate categories (Toglia and Battig, 1978; but see Richardson, 1980), produce more agreement across people about the superordinate categories to which they belong (Kintsch, 1974), and more easily elicit other kinds of associative information (Cattell, 1889; Cramer, 1968; deGroot, 1989; Jones, 1985). Concreteness effects for superordinates are especially important given the emphasis on hierarchical relations in some network models of meaning. Other research suggests that the meanings of abstract words may be less distinctive (i.e., more confusable) than concrete words. In a word association task, for example, Paivio and Begg (1971a) found that randomly paired abstract words were more likely to have shared associations (i.e., same response given to both words) than were randomly paired concrete words. The greater confusability of abstract words was confirmed by Paivio *et al.* (1988a), who had university students rate the semantic relatedness of randomly paired concrete and abstract words. The random abstract pairs received higher relatedness ratings. Subjects also do better in a Password-like game (guess a target word given single-word cues) when the targets are concrete words (Begg *et al.*, 1978). After reviewing such effects, Clark and Paivio (1989a) suggested that meanings for concrete words are particularly distinct and consistent, qualities labeled collectively as semantic coherence.

Thus, there are robust effects of concreteness and imagery value on various measures associated with word meaning. Despite the fact that these semantic measures have clear relevance to education (e.g., definability, confusability, categorizability), little research has systematically looked at the relation between concreteness and meaning for individual words from school subjects. In a comparison of several university courses, Donald (1986) found considerable variation in the average concreteness of the core concepts. For example, the concepts in natural science courses were more concrete than the concepts in social science courses, including an educational psychology class. DCT and the research reviewed above indicate that abstract words from school subjects will be more difficult to define and categorize, will be more confusable, and will show other theoretically and pedagogically interesting differences from concrete words.

With respect to the meaning of larger verbal units, such as sentences and paragraphs, experimental research has also demonstrated a major role for imagery processes. Paivio and Begg (1971b) showed that comprehension and imagery latencies are similar in magnitude for concrete sentences, and highly correlated. Relative to abstract sentences, concrete sentences generally are understood faster (e.g., Jorgenson and Kintsch, 1973; Klee and Eysenck, 1973), although not always significantly so (e.g., Paivio and Begg, 1971b). O'Neill and Paivio (1978) also found that the random exchange of words in sentences was more disruptive to the meaning of concrete than abstract sentences. Specifically, abstract sentences with words randomly substituted across unrelated sentences were rated as more comprehensible and sensible than comparable concrete sentences. One interpretation of this finding is that the meanings of abstract sentences are more vague (i.e., less definite) than the meanings of concrete sentences, and therefore less disrupted by random substitutions. In addition to research on literal language, concreteness and imagery have also been shown to be important in processing figurative sentences (Katz *et al.*, 1988; Paivio, 1971, 1986; Paivio and Begg, 1981; Paivio and Clark, 1986). Katz *et al.* (1988), for example, found that the rated imagery value of 484 metaphors correlated with a number of semantic attributes rated by university students (e.g., .79 with ease of comprehension and .80 with ease of interpretation). It has been hypothesized that figurative language may serve to concretize concepts by relating abstract topics to concrete vehicles (e.g., governments are elephants).

Educational research has confirmed the importance of imagery and concreteness for the comprehension of sentences and larger textual units. Image generation and supplementary pictures generally benefit text comprehension (see Denis, 1984), although it is not always easy to distinguish comprehension effects from closely related memory effects discussed later. Reading of educational materials seems to elicit substantial amounts of spontaneous (i.e., uninstructed) imagery. Long *et al.* (1989), for example, questioned grade 5 students about their thoughts at various points during the reading of passages from textbooks and obtained indicators of imagery on over 60% of the trials. Imagery may be especially common for emotionally arousing passages, a topic to which we return later (e.g., Sadoski, 1983, 1985; Sadoski and Goetz, 1985). Other findings indirectly support the hypothesized role of imagery in reading. Glenberg *et al.* (1987), for example, showed that university students read text faster if objects that would be spatially contiguous in an imaginal representation of the passage were mentioned together in the text, rather than separated.

The educational importance of concreteness and imagery has been further demonstrated by research on text readability. Flesch (1950), for example, measured text concreteness by the percentage of definite words (e.g., names of people, nouns that indicate a specific time) and found a correlation of -.55 between this measure and the average grade level of children who could correctly answer half of the test questions. In an experimental study, Wharton (1952; see Wharton, 1980, 1985) substituted "picture forming" words into history passages, and observed the effects on comprehension and interest. To illustrate, the sentence "With England in control of the seas and France invincible on land the war became an economic contest" was revised to "With England sweeping the seas and France overrunning the land the war lapsed into an economic tussle." University students found the high imagery texts more interesting and scored higher on a comprehension test than with the originals, even though both texts were equated on traditional aspects of readability (e.g., sentence length) and the substituted words were less familiar than the originals. Educational research has also demonstrated a relation between text readability and counts of abstract or concrete nouns (see Klare, 1974/1975; Morris and Halverson, 1938, cited in Gilliland, 1972). Other readability formulae may reflect concreteness indirectly. Some methods, for example, count the frequency of basic words in the text, but basic word lists contain few abstract words. Moreover, Cloze measures of readability, which require subjects to guess deleted words from passages (e.g., McKenna and Robinson, 1980), implicate various associative correlates of concreteness discussed earlier, such as associative strength (e.g., Cramer, 1968; deGroot, 1989; Paivio, 1968).

Although the positive effects of imagery and concreteness on comprehension are consistent with DCT, such effects are not universal (e.g., Long *et al.*, 1989). Rather than discrediting DCT, however, these qualifications often involve interactions with individual differences and other specific effects that demonstrate the strengths of DCT even more clearly than the simple effects of imagery and concreteness. Consider, for example, the fact that university students who image narrative passages read the passages more slowly than students who do not use imagery (Denis, 1982). This finding, which only appears to contradict the hypothesized benefits of imagery for comprehension, is explained by the DCT assumption that concreteness and related effects result from activation of quasi-perceptual imagery representations. Being perceptual, images can compete with reading for shared perceptual processes resulting in a slowed reading rate (Denis, 1982). Teachers who instruct their students to image while reading might therefore expect a decline in reading rate. Conversely, an emphasis on reading speed during instruction might decrease the likelihood of imaginal processing of text, with its associated benefits on comprehension and, as we shall see, memory.

Other specific phenomena consistent with DCT concern the interaction between individual differences and the use of imagery in text comprehension. As noted earlier, DCT assumes that people vary in the ease and skill with which they use nonverbal, imaginal processes. Individual differences should contribute to comprehension processes and interact with other variables, such as instructions to image. A study by Denis (1982) illustrates this line of inquiry. University students were classified as high or low imagers on the basis of a questionnaire and read descriptive passages under instructions that emphasized speed, required imagery, or were self-paced. All subjects read faster under speed than under image instructions, and there were no differences between high and low imagers in these conditions. Under self-paced instructions, however, only high imagers read at a slower rate than under speed instructions. This finding is consistent with the hypothesis that high imagers spontaneously imaged the stories, which slowed their reading rate.

The reviewed work confirms a central role for nonverbal processes in the representation and processing of text, including educational materials. Nonverbal processes presumably play an even more important role in processing the large amount of educational knowledge that is nonverbal in nature. Visual information in schools would include maps, graphs, science apparatus, geometric shapes and principles, and theoretical models for many constructs in biology and other sciences (e.g., cells, atoms, chemical molecules). Moreover, imagery is implicated in the associative structure of knowledge, to which we now turn.

Associative Structure of Knowledge

According to DCT, words derive meaning from their semantic relations with other words, as well as from images. Associative relations contribute to the meaning of all words, and are the primary source of meaning for abstract words that lack object referents (e.g., knowledge, syntax, schema, force, strategy). The essential idea is that associative relations connect words to one another, and activation of this associative structure contributes to the meaning of the words. Although similar to other models of semantic memory (e.g., schema theory, hierarchical structure), DCT emphasizes diverse associative relations between verbal representations rather than highly restricted relations (e.g., superordinate, property) between amodal abstract representations. Moreover, images can be incorporated into the meaning of concepts, especially concrete concepts, although here we emphasize verbal associative aspects of meaning. In general, associative knowledge is viewed as a complex collection of diverse associations between verbal representations, with additional referential connections to nonverbal components of meaning.

Much of the cognitive and educational research on the structure of semantic memory has emphasized superordinate networks, scripts, and other hierarchical structures in which instances or component parts converge on superordinate nodes (e.g., Bower *et al.*, 1979; Collins and Loftus, 1975; J. M. Mandler, 1984). From a DCT perspective, hierarchical structures reflect associations in which multiple words converge on superordinate labels (Clark and Paivio, 1984). Verbal representations for "dog," "cat," "lion," and other animal words, for example, become associated with the verbal representation for "animal." Early research on verbal concept learning demonstrated that activation of superordinate and related category information depends on such variables as the strength of the individual links between instances and concepts, the spacing between presentation of instances from the same category, and instructions (e.g., Underwood and Richardson, 1956). Instructions to find what is shared by a set of instances, for example, increases the likelihood that the shared category or other common feature is identified.

Many facets of educational knowledge can be conceptualized in terms of verbal associative networks. Indeed, the prototypical examples of a hierarchical network are biological and other science taxonomies in which words are linked into an associative hierarchy with multiple levels that are themselves labeled (e.g., genus: lion → family: Felidae → order: Carnivora → class: Mammalia → phylum: Vertebrata → kingdom: Animalia). Hierarchical structures have also been proposed for the representation of text (e.g., Kintsch and Van Dijk, 1978). Some texts activate preexisting semantic structures, but even when prior schemata are not available, comprehension processes construct an organized hierarchy of statements using linguistic cues to integrate sentences that vary in importance or centrality (e.g., Halliday and Hasan 1976; Kintsch and van Dijk, 1978). This research has produced detailed models of the cognitive processes that underlie mental outlines of text, such as identifying both main ideas, which are assigned central roles, and extraneous material, which can be excluded from the associative network or placed at lower levels (e.g., Williams *et al.*, 1981; van Dijk and Kintsch, 1983).

Hierarchical and related associative structures relevant to different school subjects have been measured and studied using a variety of techniques (e.g., Preece, 1976; Shavelson, 1974). In an early study, Johnson (1964) had high school students with different science backgrounds free-associate to physics terms (e.g., mass, momentum, velocity). He found that the associative structure of the terms varied with the amount and recency of instruction in science. For example, students with relevant classroom instruction were more likely to respond with other terms on the list that were related to the stimulus word by scientific principles, whereas students lacking instruction were more likely to respond with nonscience terms not on the stimulus list. A variety of methods have now been developed to obtain raw data on cognitive structures (e.g., sorting words, rating similarity). Preece (1976) has demonstrated that the different methods lead to similar conclusions about the underlying cognitive structures. Increasingly sophisticated measures are also being developed to extract various properties of associative structures from the raw data. Measures of depth (e.g., number of levels), complexity (e.g., number of branches), and other properties of cognitive structure have been related to such educational factors as instruction, expertise, and age (e.g., Fisher, 1988; Nagy, 1984).

A study by Naveh-Benjamin *et al.* (1986) illustrates the direction of this research. University students and their instructor sorted 16 terms (e.g., senile dementia, retrieval, integrity, intimacy) from a Psychology of Aging course into any order. Student sortings were done at the beginning, middle, or end of the course, and on each occasion sortings were done four times. The sortings were analyzed to produce measures for degree of organization (lack of randomness), similarity to instructor, and other aspects of cognitive structure. These derived measures were in turn correlated with class grades and showed expected changes from pre- to postinstruction. For example, associative structures became more complex (less random) and more similar to the associative structures of the instructor, and these effects were stronger for students who did well in the course than for students who did poorly.

In their study, Naveh-Benjamin *et al.* (1986) represented the cognitive structures of students and instructors as tree diagrams in which higher-level words are at the uppermost level, specific terms at the lowest level, and intervening category names between these extremes. Students and teachers often make similar outlines in the form of diagrams (see later discussion). This frequent use of spatial methods to represent relations among the verbal elements in cognitive structures (e.g., hierarchical trees, multidimensional scaling results) illustrates the intimate relation between verbal associative knowledge and imagery. Specifically, cognitive maps use spatial relations to represent the associative links among verbal representations in a nonverbal way (i.e., as a diagram). In an outline of an associative hierarchy, for example, lines between words represent class-inclusion relations and indicate that one element is a subordinate or superordinate of the other. These spatial representations for associative hierarchies are considered again when we examine memory and related educational phenomena.

The use of imagery to represent verbal associative knowledge demonstrates the strengths of DCT's emphasis on the collective and interactive effects of the verbal and nonverbal systems. The important interplay between words and images is also supported by the robust correlation between concreteness and categorizability that was discussed earlier (e.g., Kintsch, 1974; Toglia and Battig, 1978). Concrete, perceptual referents may somehow facilitate acquisition of superordinate categories and hierarchical structures.

This section has reviewed educational and cognitive phenomena that are consistent with the DCT characterization of the structure of knowledge. In short, meaning and cognitive structure result from the separate and collective actions of the imagery and verbal associative systems. These same processes explain learning and memory effects of interest to educational researchers and teachers.

LEARNING, MEMORY, AND STUDY SKILLS

The successful transmission of new skills and knowledge depends on student learning and memory processes that have received much attention from educational and cognitive researchers. From a DCT perspective, learning and remembering involve the same imagery and associative processes discussed in the preceding section on the structure of knowledge. Indeed, comprehension and memory are investigated with similar tasks, and the boundary between the two processes is often fuzzy. For example, it is unclear how much time must pass between reading a passage and answering questions before the questions tap memory rather than comprehension.

Imagery Processes in School Learning

One of the first insights associated with DCT was the role of nonverbal, imaginal processes in learning and memory tasks. Early DCT research demonstrated concreteness and imagery effects in paired-associate and other experimental learning tasks (Paivio, 1969), including memory for paragraphs (Yuille and Paivio, 1969). The predicted mnemonic benefits of imagery were explained by DCT in terms of two imagery-based processes — elaboration and organization.

The elaborative or "dual coding" explanation for imagery effects essentially states that the additive effect of imagery and verbal codes is better than a verbal code alone (Paivio, 1975b). The benefits of imaginal elaboration emerge clearly when subjects are instructed to image to-be-remembered material. Generating images produces better recall than repeated encoding conditions (i.e., repeating target words aloud or silently), and even better memory than such deep encoding operations as translating into another language (Paivio and Lambert, 1981) or generating synonyms (Vaid, 1988). Some research also suggests that traditional semantic instructions used to invoke deep levels of processing (cf. Craik and Lockhart, 1972) may also involve imagery processes (D'Agostino *et al.*, 1977).

Concreteness and imagery also benefit memory because of the special organizational capacities of the imagery system. Specifically, separate elements can be integrated into a unified or compound image that subsequently permits part of the image to reactivate the whole (Begg, 1973; Bower, 1970; Paivio, 1969). The capacity of a partial cue to reactivate the entire representation is known as redintegration. For example, the construction of an interactive image of a dog sitting on a chair permits later presentation of the dog or chair alone to redintegrate the entire image and thereby mediate retrieval of the other object. This integrative or organizational capacity of imagery was first noted in terms of the conceptual peg hypothesis, which states that concrete words are particularly effective cues for retrieving compound images of stimulus–response pairs. Consistent with this hypothesis, variation in stimulus concreteness has stronger effects in paired-associate tasks than response concreteness (Paivio, 1963). Integration also provides a plausible explanation for the effectiveness of interactive images in mnemonic techniques and other memory strategies.

Marked effects of concreteness and imagery on memory for educational material have been reported, and the results are generally consistent with the experimental research and with the DCT analysis. The interactive images in the keyword mnemonic technique, for example, link to-be-learned translations with familiar keywords that sound like the unfamiliar vocabulary words. Later presentation of the new word, or its English equivalent, cues retrieval of the keyword, which in turn reintegrates the image and the translation. This technique has been shown to facilitate vocabulary learning in various educational domains, including native- and second-language learning (Atkinson, 1975; Levin and Pressley, 1985). Keyword and other imagery techniques have considerable relevance for education (see Bellezza, 1981; Paivio and Desrochers, 1981; Roediger, 1980) because new vocabulary is a major element in school learning, perhaps especially in languages and sciences (Eylon and Linn, 1988). Even 60 years ago, a sample of high school biology notebooks contained over 600 different science terms that students were expected to know (Baird, 1931).

Consistent with our earlier analysis of meaning, imagery and concreteness also play an important role in memory for text (Anderson, 1974; Begg and Paivio, 1969). Concrete phrases, sentences, and paragraphs are remembered better than abstract text (e.g., Yuille and Paivio, 1969). Moreover, subjects receiving imagery instructions remember more than subjects who do not receive such instructions, and subjects who report spontaneous images remember more than subjects who do not report images (see Denis, 1984, for a review). Sadoski (1984), for example, found that recall scores for a basal reader story correlated .49 with number of text-specific images reported by grade 3 and 4 students. Further evidence for the benefits of imagery come from research on the role of mental models in memory for text (e.g., Gentner and Stevens, 1983; Johnson-Laird, 1983), inasmuch as mental models are described as percept-like representations (i.e., images) for situations described by text (Glenberg *et al.*, 1987). Constructing or processing a supplementary map, one kind of mental model or image, improves memory for related text (Dean and Kulhavy, 1981); and, more generally, mental models (e.g., diagrams for scientific constructs) facilitate memory for ideas and generalization of principles from explanatory texts (Mayer, 1989).

The preceding studies report effects for concreteness of the target information, but memory is also influenced by the concreteness of such supplementary material as advance organizers (Ausubel, 1960). Corkill *et al.* (1988), for example, observed that undergraduate education majors recalled more information about 1200- and 5000-word passages of text (e.g., chapter on introductory linguistics) when preceded by concrete advance organizers as opposed to abstract advance organizers. Abstract organizers, in fact, did not facilitate memory relative to no organizer. This superiority of concrete advance organizers is analogous to the early work on concrete words as conceptual pegs and may similarly result from the special capacity of concrete words for redintegration of compound images. Imagery may also contribute to other manipulations that improve sentence memory, such as precise elaborations. Bransford *et al.* (see Bransford *et al.*, 1982, for an overview) demonstrated that precise elaborations of sentences facilitated associative learning by both university and fifth-grade students. For example, completing the sentence, "The tall man took the cookies" with an elaboration relevant to height (e.g., "from the top shelf") produced better memory for what the tall man did than a completion in which height was incidental (e.g., "from the counter"). Using a similar task, Pressley *et al.* (1987) demonstrated that student-generated elaborations (i.e., asking why certain facts might be associated with a particular concept) are particularly effective ways to promote associative learning in undergraduates. Precise elaborations and other manipulations in the text memory literature may help memory in part because they elicit more imagery than do control conditions.

Another kind of evidence for the important mnemonic role of imagery in educational learning comes from research on study skills. A number of behaviors associated with the quality of study skills can be understood in terms of imagery processes. An elaborative imagery factor emerged from a factor analytic study of Kulhavy and Kardash (1988). They obtained self-reports from undergraduate education students about the frequency with which they engaged in various study activities. The elaborative imagery factor included such imaginal operations as generating mental images and writing examples for school material, and accounted for much variation in self-reported study activities. One benefit of generating examples may be that they evoke images for personal experiences or imagined concrete events. Items relevant to imaginal processing also occur on standardized tests and behavioral analyses of study skills and habits. The Study Report Form (Johnston, 1975), for example, is a behavioral based system developed for university students to record time spent in various study practices. The form includes items related to elaborative imagery (e.g., writing examples). Schmeck's Inventory of Learning Processes (Schmeck, 1983; Schmeck *et al.*, 1977; Schmeck and Ribich, 1978) similarly contains an elaborative processing factor that includes such items as the use of visual imagery. Schmeck (1983) reviews evidence that elaborative processing scores differentiate students of different abilities (e.g., Moss, 1982), and correlate with grades and experimental learning tasks (e.g., Schmeck *et al.*, 1977). Elaborative processing scores also correlate positively with individual differences in imagery ability (Schmeck and Ribich, 1978), consistent with an imagery explanation for the memory effects.

Imagery processes are further emphasized in books and programs designed to improve learning and study skills. An early text by McMurry (1909) included a chapter on supplementing thought, which recommended the use of such imagery-related methods as imagination, elaboration, making illustrations, experiencing the material, and listing details. Contemporary study guides (e.g., Robinson, 1970) and study skills programs stress similar processes. Dansereau *et al.* (1979), for example, included imagery and network construction methods in their program. The network or cognitive mapping methods use spatial imagery to represent verbal associative structures (see sections on associative processes in the structure of knowledge and in memory). Imaginal elaboration is also a central component in the cognitive learning strategies program of Weinstein and her colleagues (e.g., Weinstein *et al.*, 1979) and in Wittrock's model of generative learning (e.g., Wittrock and Alesandrini, 1990).

Much of the research on study skills involves older students, but elaborative imagery is relevant to several strategies that have been demonstrated to improve memory and comprehension in younger students. For example, a recent review by Pressley *et al.* (1989b) cited such effective strategies as constructing internal images for the meaning of text, and comparing your own life with the text, both of which involve imagery. Similar elaborative processes are also central components in models of effective reading (e.g., Gagne, 1985, Ch. 7) and writing (Kellogg, 1988) that are designed for use with students of different ages.

These diverse findings clearly demonstrate the practical mnemonic benefits of imagery for educators. Nonetheless, many questions remain about the specific conditions under which imagery benefits memory, and about the mechanisms that underlie those benefits. For example, the benefits of mental models vary with student knowledge and ability (e.g., Mayer, 1989; Wittrock and Alesandrini, 1990), and the addition of concrete details does not always facilitate memory for abstract passages (e.g., Hidi and Baird, 1988). As noted earlier, however, the DCT emphasis on individual differences and attributes of materials lends itself to principled explanations for such findings. Riding and Calvey (1981), for example, measured verbalizer-imager learning styles by the relative speed with which 10- to 11-year-old children could answer imaginal and verbal questions about a prose passage. The children later learned four passages varying from a highly semantic (i.e., verbal) passage to a highly visual passage. Children showed no overall differences in their level of recall, but high imagers remembered the highly visual passage better and high verbalizers remembered the highly semantic passage better. These results are consistent with DCT predictions and demonstrate the strengths of a theoretical perspective that accommodates attributes of learning materials, individual differences, and instructions.

Other unresolved questions concern the theoretical mechanisms that underlie imagery effects. Some direct tests of the assumption that imagery enhances integration of concrete sentences have produced negative results (e.g., Marschark, 1985; Marschark and Paivio, 1977), and alternatives to DCT have been proposed for imagery and concreteness effects in experimental memory tasks (e.g., Marschark and Hunt, 1989; Marschark *et al.*, 1987). These issues cannot be resolved here, but we do note that the verbal and imaginal processes of DCT are quite complex and still not fully understood, and, as just noted, that the theory ascribes a central place to individual differences, item attributes, and other factors that complicate simplistic applications of the theory. Interpretation of negative results is also complicated by the fact that there is still much to learn about the basic cognitive mechanisms that underlie many memory tasks, including mnemonic techniques of interest to educators (e.g., Desrochers and Begg, 1987; Paivio and Desrochers, 1981). Moreover, some problematic phenomena, such as integration effects for abstract materials, can be explained by considering the role of DCT's verbal components in memory.

Associative Processes and Memory

DCT states that imagery and verbal associative processes jointly determine learning and memory performance, with direct and indirect associations between verbal codes influencing storage and retrieval of information. One robust finding that reflects associative processes is the effect of organization on learning in various verbal learning paradigms. For example, lists of related words from superordinate categories are better remembered than unrelated words (e.g., Bousfield, 1953), and paired associate learning increases with the strength of direct associations between the two terms (Murray, 1982) and with the probability that both words are indirectly linked by a shared associate (Miller, 1970). With respect to memory for categorized lists of words and related organizational effects, DCT emphasizes the contribution of indirect verbal associations in which multiple words or phrases converge on a shared associate (Clark and Paivio, 1984). The shared associate can subsequently act as a retrieval cue for the specific instances that originally elicited it. Retrieval of dog, horse, and tiger, for example, would be facilitated by the convergent associate "animal" being activated during study and serving as a retrieval cue during recall.

Similar associative processes contribute to memory for text and other educationally relevant material. Memory for text, for example, benefits from preexisting associative structures, such as a familiar schema or script, and information central to the main theme of the passage is remembered particularly well (e.g., Anderson, 1977; Bower *et al.*, 1979; J. M. Mandler, 1984). Associative structures also explain effects on learning and memory of advance organizers (Ausubel, 1960), statements of learning objectives, and related methods that involve priming the underlying structure of text. Although much of this research involves use of available semantic structures, readers also impose associative organizations on text material that lacks an obvious structure. Memory is better, for example, for statements that are at a higher node in a text's inferred structure than for statements at lower levels (Kintsch and Keenan, 1973; Meyer, 1977).

The mnemonic benefits of schema, scripts and categories, and related organizational effects, are consistent with the DCT associative model. At one time, schematic organization was thought to produce better memory than categorical organization (Rabinowitz and Mandler, 1983), suggesting different underlying mechanisms. However, Khan and Paivio (1988) demonstrated that lists organized categorically or schematically produce equal recall when other aspects of the learning situation are equated. Specifically, university students recalled category and schema lists equally well when both lists contained labels for the clusters (e.g., animals, living on a farm) or when neither contained organizing names. Comparisons favored schematic organizations only when schematically organized lists with labels were compared to category lists without labels, as in the Rabinowitz and Mandler (1983) study. Thus, the findings are consistent with verbal associative views of memory for organized materials (see also Khan, 1989).

Research on study skills further demonstrates the importance of verbal associative structures and their spatial representation. Such associative operations as outlining, summarizing, and writing important points constitute one factor in Kulhavy and Kardash's (1988) analysis of study activities. Items on organization of notes are also included on the Survey of Study Habits and Attitudes (Brown and Holtzman, 1967) and the Study Skills Test (Raygor, 1970). Constructing outlines and other items that implicate verbal and imaginal associative processes are part of the Study Report Form (Johnston, 1975), and finding related themes and organizing ideas is part of the deep processing factor on Schmeck's (1983) Inventory of Learning Processes. An associative explanation for the deep processing factor is supported by evidence that it correlates with ability to organize lecture material into associative hierarchies (Ribich, 1977, cited in Schmeck, 1983). Deep processing also correlates with student abilities, grades, and performance on other relevant tasks (e.g., Moss, 1982; Schmeck, 1983; Schmeck *et al.*, 1977).

The mnemonic benefits of verbal associative processes are emphasized in books and programs designed to improve study skills. A chapter in McMurry (1909) on organization of facts included such associative strategies as outlines, headings, note-taking, grouping facts, finding relations, subordination, and hierarchies; and similar processes appear in contemporary study guides (e.g., Robinson, 1970), study programs (e.g., Weinstein *et al.*, 1979), and theories of effective studying (e.g., Wittrock and Alesandrini, 1990). Study guides also recommend ways to represent verbal associative structures, including imagery-based methods. Spatial outlines and graphic organizers are used in schematizing and networking study techniques (e.g., Buzan, 1974; Holley and Dansereau, 1984; Novak and Gowin, 1984), and the network construction methods taught by Dansereau *et al.* (1979) involve imaginal representations for verbal associative structures. To illustrate, a cognitive map of a lesson or chapter on Japan might be summarized as a tree diagram with Japan as the top heading, such subheadings as geography and history at the next level, and so on. Graphic representations for associative structures have also been examined as text supplements (Guri-Rozenblit, 1989; Simmons *et al.*, 1988). These spatial methods blur the division between imagery and verbal associative processes, and may capitalize on the capacity of the nonverbal system to integrate spatially contiguous events, including verbal labels, in an associative network.

Associative structures and their spatial representations appear to benefit students of all ages. Much of the research reported above was concerned with older students, but the Pressley *et al.* (1989b) review concluded that a number of verbal associative methods were effective with young children, including summarizing text and constructing story maps. Associative components to the structure of text are also central components in models of reading (e.g., Gagne, 1985, Ch. 7) and writing (Kellogg, 1988) relevant to students of all ages.

We have reviewed the effects of both imaginal and verbal associative factors in learning and memory. Although treated here largely as separate processes, DCT emphasizes their collective and interactive effects on behavior. We have already seen that verbal associative structures can be represented imaginally. It also seems likely that scripts and related associative structures benefit from spontaneous imagery of script events. That is, using scripts to encode episodes (e.g., a visit to the library, a school day, a science experiment) may evoke visual images of typical events in the script (e.g., setting up the equipment, taking measurements, writing down results). Imagery may also play a variety of roles in text cohesion, another aspect of associative meaning (Halliday and Hasan, 1976). Synonyms facilitate text integration, for example, and concrete synonyms, which share a common image, are more strongly connected to one another than are abstract synonyms (Clark, 1978, 1984; Paivio *et al.*, 1988b). These examples involve imaginal effects on associative processing, but verbal associative processes also influence imagery. The ease of generating interactive images, for example, depends in part on associative relatedness, suggesting that interactive imagery is not a pure nonverbal process (Paivio *et al.*, 1988a).

Associative processes also explain problematic imagery results discussed earlier, such as failures to find evidence for the special integrative role of imagery in memory for sentences and other verbal materials (e.g., Marschark and Paivio, 1977). Paivio and Walsh (summarized in Paivio, 1991) recently tested the hypothesis that verbal associations between abstract words provide integrative retrieval cues that partly mask the integrative benefits of imagery. Cued recall of concrete and abstract pairs varying in associative relatedness was compared to free recall of the same pairs. The superiority of cued recall over free recall is one measure of integration (Begg, 1973). Paivio and Walsh found that the differences between cued and free recall were substantial and similar for concrete-related, concrete-unrelated, and abstract-related pairs, but that abstract-unrelated pairs showed little evidence for integration. This finding demonstrates that high imagery is sufficient for integration of concrete words, even in unrelated pairs, whereas strong verbal associations are necessary for the integration of abstract words.

In conclusion, many findings support the hypothesis that memory for words and text benefit from elaborative imagery, concreteness, and associative organization, although the collective effect of these processes are complex and a number of important questions remain unresolved. Moreover, the DCT emphasis on verbal and imaginal processes fits well with several cognitive models of learning and memory in the educational domain (e.g., Schmeck, 1983; Weinstein *et al.*, 1979; Wittrock and Alesandrini, 1990).

OTHER COGNITIVE TOPICS IN EDUCATION

The structure of knowledge and the processes that underlie learning and memory are basic to many aspects of educational psychology. Here we show that DCT provides a unifying perspective on two other cognitive aspects of education: the effectiveness of instruction and educational testing.

DCT and Effective Instruction

Preceding sections have demonstrated the importance of imagery, concreteness, and verbal associative processes for comprehension and memory of school material. It is expected, therefore, that these same factors influence the effectiveness of teaching. We consider imagery and verbal associative factors in turn.

The research demonstrating that imagery and concreteness play central roles in the representation and acquisition of knowledge is directly relevant to instructional practices. The positive effects of concreteness and imagery on the readability of texts and on memory, for example, generalize to oral transmission of information in the classroom. That is, lessons containing concrete information and evoking vivid images will be easier to comprehend and remember than lessons that are abstract and not image-arousing. Moreover, the same imagery manipulations that benefit memory for text should also benefit memory for orally presented information as in classroom lessons. Levin and Berry (1980), for example, asked fourth graders to recall information from tape-recorded newspaper stories. Children who listened to the stories while viewing relevant pictures recalled more than children who only heard the stories.

The instructional benefits of imagery and concreteness also appear in works on teaching skills and effectiveness. An early and extensive effort to document teaching activities was the Commonwealth Teacher-Training Study (Charters and Waples, 1929). In this study, teachers, school administrators, and other participants generated a large number of teaching traits and activities. The resulting items were subsequently categorized and rated on such dimensions as importance. One large category of activities was called "Teaching Subject Matter," which included many activities suggesting a direct role for concreteness and imagery in teaching. Pedagogical practices related to imagery included using effective pictures, diagrams, models, and other illustrations for lessons, and showing relationships between school subjects and events in real life. These recommendations parallel imagery-related suggestions discussed earlier in the context of effective study strategies.

The relevance of imagery and concreteness to teaching is further supported by empirical studies of teachers in the classroom. Student ratings of teacher behaviors, for example, produce evidence for factors relevant to imagery-concreteness. At the university level, Murray (1983a, 1985) found that such behaviors as "uses concrete examples to explain abstract ideas" and "relates subject matter to current events" loaded on a clarity/concreteness teaching factor. In research on the effectiveness of elementary mathematics teachers, Ebmeier and Good (1979) found that teachers vary in their degree of abstractness, defined as "using abstract concepts or techniques or materials with which the students have little familiarity," and that teachers who were more educated and secure than other teachers obtained low scores on this dimension (i.e., they were high on concreteness). Given the evidence cited earlier for a relation between concreteness and such communication variables as fluency and distinctiveness, the relevance of concreteness to instruction may also be reflected in other correlates of teaching effectiveness, such as presentation clarity (Frey *et al.*, 1975) and (negatively) vagueness (Dunkin and Doenau, 1980; Hiller *et al.*, 1969).

This research on teacher effectiveness has led educational psychologists and others concerned with effective teaching to advocate instructional methods that can be conceptualized in terms of imaginal processes. Woolfolk (1987, pp. 423–425), for example, includes the following recommendations to improve the clarity of teaching and reduce vagueness: "Use concrete examples or analogies that relate to the students' own lives," "Use models, examples, and illustrations," and "Use specific (and, if possible, colorful) names." The importance of concreteness has also been emphasized in writings on effective lecturing at the university level (e.g., Clark and Clark, 1970, originally published in 1959), although Clark and Clark make the important point that the concrete illustrations must be relevant to the lecture.

Theoretically, DCT suggests that visual illustrations, the use of concrete and personal examples, and related teaching behaviors help comprehension and retention of lessons by activating concrete referents and increasing the arousal of mental images in students. Consistent with these expected benefits, ratings of teacher concreteness/clarity do often correlate with student achievement (e.g., Frey *et al.*, 1975), and with ratings of teacher and course effectiveness (Murray, 1983a). Dunkin and Doenau (1980) also reported that teacher vagueness, the opposite of concreteness and clarity, had negative effects on student achievement. But measures of teacher clarity do not always correlate significantly with final exam performance or ratings of the amount learned in the course, although the correlations are generally positive. Murray (1983a), for example, found that average clarity ratings for 36 introductory psychology instructors correlated only .16 with average final exam performance and .29 with students' average ratings for amount learned in the course.

Similar complexities were observed in the effects of concreteness and imagery on text comprehension and memory. As was noted there, such complexities can be explained by a DCT analysis of the cognitive mechanisms underlying imagery and concreteness effects. A similar analysis of instructional effectiveness suggests possible reasons for inconsistent results and directions for future research. If concrete examples facilitate memory by evoking images, for example, then researchers could measure student imagery and see whether effects of instructional concreteness occur more strongly or only for students who actually had mental images of the examples. Moreover, the likelihood of concrete examples enhancing image generation during lectures will vary as a function of course content (e.g., its concreteness) and individual differences (e.g., imagery abilities of students).

In addition to imagery, DCT states that verbal associative processes contribute substantially to the effectiveness of instruction. Evidence is generally consistent with this premise. In their early study of teaching activities, Charters and Waples (1929) found that the "Teaching Subject Matter" category included many activities related to what we call associative organization. For example, teachers develop outlines for their lessons, arrange units into orderly sequences, try to summarize the ideas that they are teaching, and generally attempt to organize their subject matter knowledge.

Indicators of verbal associative organization have been identified in research on effective teaching (e.g., Frey *et al.*, 1975; Marsh, 1982), although imagery may contribute here as it does to organizational effects in comprehension and memory. Associative factors on teacher rating scales include such behaviors as "puts outline of lecture on the board" and "gives preliminary overview of lecture" (Murray, 1983a, 1985). The explicit use of free association and spatial mapping techniques to prepare lectures and lessons (Brown and Atkins, 1988) provides further support for the importance of associative structure in teaching. That is, Brown and Atkins recommend that lectures be prepared by free-associating to the main theme of the lecture and then arranging the ideas into a meaningful organization using a tree diagram or some other spatial representation for the subject matter. Spatial representations for cognitive structures of teachers are also obtained in many studies of student cognitive structures that were described earlier, presumably on the assumption that the cognitive structures of teachers relate closely to the objectives of instruction.

Research on associative factors in instruction has led to recommendations that now appear in educational psychology and related teacher education courses. Woolfolk (1987, pp. 423–425), for example, includes the following suggestions to improve teaching: "Organize your lessons carefully," "Work on an outline with the class," "Break the presentation into clear steps or stages," and "Signal transitions from one major topic to another." Hierarchical outlines are also emphasized in characterizations of effective university instruction. Clark and Clark (1970, p. 13), for example, suggest that lecturers should "aim at getting home a limited number of points, well defined, properly emphasized and arranged in some sort of logical order."

From a DCT perspective, verbal associative organization and related imagery methods can benefit instruction in several ways. One benefit for student learning is that outlines and related behaviors parallel the verbal associative structures that underlie knowledge and its acquisition. A teacher who presents a lesson on Japan in terms of well-identified topic headings (e.g., geography, history) and subheadings (e.g., major landforms, climate) is enhancing the likelihood that category names are being acquired, and that links are being formed between category names and specific pieces of information. This organization will benefit comprehension and subsequent retrieval. Such associative strategies as tree diagrams may also benefit learning because they promote integrative imagery and thereby facilitate cued retrieval. For example, students who saw a hierarchical outline for a lesson on Japan or were encouraged to develop their own outlines could then use a mental image of that outline to study, to retrieve the information on a test, to organize their answer for an essay question, and to perform other educational tasks.

This theoretical model for the benefits of associative structures and mental outlines is consistent with research reviewed earlier on the role of verbal associative and imaginal organization in text comprehension, memory, and study skills. Such mechanisms explain why the use of effective associative organization in lessons correlates in some nonexperimental studies with measures of student achievement (e.g., Frey *et al.*, 1975) and with ratings of teacher and course effectiveness (e.g., Murray, 1983a). But as noted earlier for teacher clarity, the relations are not always significant (e.g., Murray, 1983a; Sullivan and Skanes, 1974). Studies that manipulate teacher behaviors have also produced support for the cognitive benefits of lesson organization. In one experimental study, Clark *et al.* (1979) compared sixth-grade teachers using high lesson structure (e.g., stating objectives at beginning of lesson, outlining content) with the same teachers using low lesson structure (absence of structural behaviors). Structuring had positive effects on several measures of student achievement.

DCT would approach these somewhat varied outcomes and the more general problem of understanding teaching effects by designing studies that would assess the putative underlying mechanisms. In the case of organizational effects, for example, researchers could examine the quality of students' notes when teachers did or did not use outlines (e.g., presence or absence of schematic outlines in notebooks), measure student cognitive structures using sorting and other methods discussed earlier (e.g., degree of structure, similarity to instructor), and assess interactions between lesson organization and relevant individual differences (e.g., verbal and imagery abilities, study skills). Such research would reveal the cognitive mechanisms underlying instructional effects, including the relative contributions of verbal and nonverbal processes. An analytic approach based on DCT may complement other efforts in educational and cognitive psychology to explain instructional effects by basic cognitive processes (e.g., Gliessman *et al.*, 1988; Rosenshine and Martin, 1974; Winne and Marx, 1977).

DCT and Educational Testing

We have already observed that individual differences can qualify effects of instructions, materials, and other variables in cognitive and educational research. Testing of individual differences is a major activity in education and serves many purposes, including student selection into special programs and differential instruction within the classroom (Salvia and Ysseldyke, 1988). A large part of educational assessment involves tests of intelligence, achievement, and related cognitive processes. DCT provides a useful framework for thinking about cognitive tests. In particular, the DCT hypothesis of distinct verbal and nonverbal cognitive systems corresponds to analogous distinctions in most tests and theories of intelligence.

With respect to the nonverbal or imagery system, intelligence tests usually include subscales that measure nonverbal abilities, and factor analyses of general test batteries identify a perceptual-spatial ability factor that is distinct from verbal abilities (Anastasi, 1988). Nonverbal or imaginal processes contribute to the Performance scales of Weschler's test (Wescheler, 1974) and of Jackson's (1984) Multidimensional Aptitude Battery, and to the simultaneous processing dimension (e.g., Das *et al.*, 1975; see Paivio, 1975c) that underlies the Kaufman Assessment Battery for Children (Kaufman and Kaufman, 1983). More specifically, the Wechsler tests include such imaginally laden tasks as object assembly and block design. Jackson's test also has a paper and pencil version of the mental rotation task, which has been used in many experimental studies of imagery processing and involves the comparison of figures (e.g., shapes or letters) at different orientations (e.g., tilted 45 degrees left or right). Models of intelligence other than two-factor theories also assign a major role to nonverbal abilities. With respect to Guilford's (1967) Structure of Intellect, for example, imagery and spatial abilities underlie the Figural Transformations component, which includes block rotation, Minnesota Paper Formboard, and other specific measures of imagery abilities (see Paivio, 1986, Ch. 6).

The verbal side of DCT is reflected in language measures on intelligence and related tests, including the Verbal scales of the Wechsler tests (Wechsler, 1974) and of Jackson's battery (Jackson, 1984), the successive processing dimension of the Kaufman (Das *et al.*, 1975; Kaufman and Kaufman, 1983; see Paivio, 1975c), and various components in Guilford's model (Guilford, 1967). Factor analytic studies have produced evidence for a distinct verbal ability factor (Anastasi, 1988). Examination of verbal tasks demonstrates the central role for verbal representations and related associative processes. *Similarities* items on the Wechsler tests, for example, require the identification of commonalities between two words (e.g., car and boat) and measure convergent associative processes. That is, correct responses require the activation of a shared associate of the two words (e.g., transportation). Verbal tests that require the production or identification of synonyms, antonyms, and other related terms similarly involve verbal associative processes.

In addition to its correspondence with general taxonomies of ability, DCT's theoretical mechanisms permit detailed models for a wide variety of cognitive tasks used in educational assessment. Models for different tasks are constructed from hypothetical networks of associatively and referentially related mental representations for verbal and nonverbal components of the task. This analytic approach is consistent with other efforts in educational and cognitive psychology to explain test performance in terms of underlying cognitive processes (e.g., Glaser, 1981; Pellegrino, 1987; Ronning *et al.*, 1987; Sternberg, 1981). To illustrate, the *Similarities* task discussed earlier can be modeled in terms of verbal representations for instance and superordinate names, and associative relations between the instances and the superordinates. Failure on the task can result from breakdowns in various components of the model, such as missing representations (e.g., no word for "transportation"), absent connections (e.g., "boat" not connected to "transportation"), or failure to suppress interfering associations (e.g., "water").

A second illustration of how DCT can model specific assessment tasks is provided by picture vocabulary tests, which are used widely to assess child language abilities and dysfunctions in early grades, in special education and clinical settings, and in many research studies (e.g., Denckla *et al.*, 1981; Snowling *et al.*, 1988; van der Wissel, 1988). Performance on production tests that require active naming, such as the Expressive One Word Picture Vocabulary Test (Gardner, 1979), varies with factors that are associated with a DCT model of picture naming. For example, pictures with a single label (e.g., apple, scissors) are easier to name than pictures with multiple labels (e.g., cat, purse). This effect of response uncertainty (i.e., number of different names) has been observed on the probability of errors (Johnson and Clark, 1988) and on reaction times in experimental research on naming (e.g., Lachman, 1973; Paivio *et al.*, 1989). It has been hypothesized that pictures with many names have multiple referential connections and are difficult or slow to name either because activation is diffused across the alternative pathways, or because the alternative responses that are activated compete with and inhibit one another (Clark, 1988; Clark and Johnson, unpublished; Paivio *et al.*, 1989). A similar mechanism, namely interference from competing instance names, contributes to the exceptional difficulty young children have on naming tests that require the retrieval of superordinate names (Johnson and Clark, 1988; see also Clark and Johnson, unpublished). For example, young children might have difficulty calling a picture of an apple "fruit" because they cannot suppress the more available label "apple."

DCT also provides analytical models for nonverbal tests and for educational correlates of imagery ability. Nonverbal tasks involve the special properties of the imaginal system described earlier, such as the capacity to integrate and redintegrate information. One property that has been particularly important in the individual difference domain is the capacity of images for spatial transformations. Many spatial tests, such as mental rotation tasks, involve dynamic transformations of spatial stimuli (e.g., Lohman and Kyllonen, 1983). Gender differences in imagery ability are particularly robust on such dynamic imagery tasks (e.g., Linn and Hyde, 1989; Maccoby and Jacklin, 1974; Paivio and Clark, 1991). Understanding how imaginal transformations are performed could therefore shed light on some controversial issues associated with individual differences in imagery ability and mathematics education, including controversial relations between gender, mathematics, and imagery ability (e.g., Benbow and Stanley, 1983; Burnett *et al.*, 1979; Hyde, 1981; Linn and Hyde, 1989), and the experiential or biological origins of any differences (e.g., Baenninger and Newcombe, 1988; Kimura, 1987). The mechanisms underlying imagery tasks, mathematics, and the relation between imagery ability and mathematics-science (e.g., Paivio, 1983a; Shepard, 1978) are also relevant to other educational phenomena, such as mathematics-specific learning disabilities (Ozols and Rourke, 1988). Moreover, imagery and other DCT mechanisms have been used to develop a general theory of number processing (Clark and Campbell, 1991).

Individual differences in imagery abilities are also relevant to many of the educational phenomena discussed in earlier sections of the paper. Reaction time studies have demonstrated that people who score high on measures of imagery ability and habits image more quickly than people who score low on such measures, perhaps especially for abstract words (Ernest and Paivio, 1971). This finding explains why individuals of high imagery ability are more likely to use imagery when reading normally, whereas individuals of low imagery ability only image when instructed (Denis, 1982). Imagery latencies also explain individual differences in memory effects of imagery (e.g., Schmeck and Ribich, 1978). Specifically, people who find it effortful and slow to generate images are not likely to spontaneously image to help their comprehension and memory, and indeed forced use of imagery might have a negative effect on their performance. Analytic studies of the role of word attributes in image generation tasks (e.g., Paivio *et al.*, 1989) also further our understanding of individual differences, by revealing the mechanisms involved in imaging (e.g., word identification, activation of referential connections to images) and by providing precise information about the kinds of items that differentiate high and low imagers.

A final contribution of DCT to individual difference research follows from its emphasis on the role of experience in human cognition. Because experience and practice determine the ease and likelihood that imagery and other cognitive processes are activated, performance depends on mental habits or preferences as well as abilities. The Individual Differences Questionnaire (IDQ; Paivio, 1971; Paivio & Harshman, 1983) was developed to assess tendencies or preferences for processing information either verbally or imaginally, Respondents are asked, for example, to what extent statements such as the following are true of them: "When remembering a scene, I use verbal descriptions rather than mental pictures" and "I often use mental pictures to solve problems." Other questions ask about how well people think they can perform various verbal and nonverbal operations. IDQ scores correlate somewhat with relevant measures of ability (e.g., Ernest and Paivio, 1971), but also show some unique effects. For example, scores for verbal and imagery habits tend to be uncorrelated, whereas verbal and nonverbal abilities are positively correlated.

In this section we have shown that DCT is relevant to educational research on instruction and assessment. Imagery and verbal associative processes provide a unifying framework that helps organize much research on effective teaching strategies (e.g., use of examples, outlines) and educational testing (e.g., verbal vs. nonverbal abilities, picture vocabulary tests). Moreover, DCT permits the development and testing of detailed models for the effects of instructional variables and for performance on specific tasks used in educational assessment. The usefulness of DCT for describing instructional and testing phenomena demonstrates how general its basic theoretical mechanisms are, at least with respect to cognitive domains.

DCT AND "NONCOGNITIVE" EDUCATIONAL TOPICS

The preceding sections of this article have concentrated on topics that are primarily cognitive in nature, but DCT also provides a foundation for understanding less cognitive phenomena, such as emotions and motor skills. This is not surprising, given the heavy emphasis on cognitive elements in contemporary models for both emotions and motor skills. It is therefore something of a misnomer to label these topics as "noncognitive," hence the quotes.

A DCT View of Emotion and Education

DCT conceptualizes emotion as a complex pattern of activation among interconnected nonverbal and verbal representations. The nonverbal components of emotion include visual images for affect-related objects (e.g., school, teachers, notebooks), kinesthetic images involving facial and other skeletal muscles (e.g., smile, frown, clenched fist), and somatic or autonomic images associated with visceral reactions (e.g., queasy stomach, heart rate). Much research has demonstrated the importance for emotional experience of facial expressions (e.g., Schwartz *et al.*, 1979) and visceral reactions (e.g., G. Mandler, 1958, 1984; Schwartz *et al.*,. 1978). Imagery is also a central element in several theoretical and clinical models of emotion (e.g., Bandura, 1969; Craighead *et al.*, 1976, pp. 145–151; Lang, 1979a,b).

The DCT model of separate verbal and nonverbal systems leads to the inference that visual images for objects may be more directly connected to other nonverbal components of emotion (e.g., somatic and kinesthetic images) than are verbal representations for objects. Consistent with this expectation, people are faster to choose the more pleasant of two objects when pictures are shown than when object names are shown (Paivio, 1978; Paivio and Marschark, 1980), and pictures elicit higher ratings of emotionality than do words and fewer reports of no emotion when subjects are asked to generate emotional reactions to stimuli (Clark and Paivio, 1989b). Preferential access to affect by nonverbal stimuli is also suggested by the finding that spatial questions, such as "Picture and describe the last situation in which you laughed," elicit stronger emotion ratings and more facial muscle activity from undergraduate subjects than do verbal questions, such as "Give me a synonym for the word happy" (Schwartz *et al.*, 1979). Moreover, high imagers demonstrate stronger physiological reactions to imagined emotional situations than do low imagers (Lang, 1984).

The central role of imagery in emotion is further supported by research on emotions relevant to education, such as achievement motivation and evaluation anxiety. With respect to achievement motivation, goal-related images (e.g., receiving a diploma at graduation, a teacher smiling while returning a paper) motivate students and others to persist with tasks that have long-term benefits (e.g., Singer, 1966). Projective measures of achievement motivation are based on verbally described images elicited by pictures (McClelland *et al.*, 1953). Imagery methods have also been used in many studies to enhance motivation in athletes (see Paivio, 1985, for an overview), an approach that could promote motivation and persistence in students. For example, students might be explicitly trained to mentally image success outcomes for their academic efforts. A positive correlation between student interest and imagery has also been reported in research on text processing (Sadoski and Goetz, 1985; Wharton, 1980). That is, concrete text that evokes imagery tends to be more interesting than abstract text. Analogous effects may contribute to the positive effects of imagery and concreteness on teaching effectiveness (cf. Clark and Clark, 1970).

Another emotion with considerable educational influence is anxiety, in particular, evaluation anxiety. One component of evaluation anxiety, sensitivity to audiences or "stage fright" (Paivio, 1965; Paivio and Lambert, 1959), has been measured in high school and university students using imagery-based projective measures similar to those used to measure achievement motivation. That is, respondents describe imaginary stories for pictures that depict audience situations. Imagery is also involved in many psychological treatments for such affective disorders as evaluation anxiety (Hembree, 1988). Systematic desensitization, for example, requires students to maintain a relaxed bodily state while mentally imaging a graduated series for the feared object (e.g., teacher announcing a test in two weeks, studying the night before, walking in to take the test, trying to answer a difficult question). The relaxed state in systematic desensitization and other cognitive treatments may also be induced using imagery techniques (e.g., image yourself relaxing on a beach, or feel the muscular relaxation flowing through your body).

As in the cognitive domains that we have examined, the DCT account of emotion includes verbal elements, such as emotion words (e.g., worry, bored), general evaluative terms (e.g., good, bad), labels for bodily states (e.g., tense, queasy stomach), and names for affect-related objects (e.g., school, test, mathematics) and events (e.g., quit, graduate) (Davitz, 1969). Similar verbal codes or their abstract equivalents are elements in other theories of emotion (e.g., Bandura, 1969; Craighead *et al.*, 1976, pp. 145–151; Lang, 1979a,b).

Verbal labels relevant to emotion are linked by associative connections to one another and by referential connections to the imagery system. Free association, sorting, and related tasks have produced evidence that emotion terms may be organized in a hierarchical structure similar to those found in cognitive domains, and several theories of emotion emphasize such associative structures (e.g., Bower, 1981; G. Mandler, 1975, 1984). Storm and Storm (1987), for example, developed a taxonomy of emotion terms with three categories of negative terms: shame and sadness (e.g., humiliated, discouraged), anxiety and fear (e.g., worried, tension), and hostility (e.g., anger, rebellious); two categories of positive terms: interpersonal (e.g., admiration, concern) and not interpersonal (e.g., pride, hope); and a final category of relatively neutral terms in which arousal and cognition are salient (e.g., alienated, absorbed). Items in all of these categories, such as the examples given, are relevant to education, which would benefit from a fuller understanding of the associative meaning of these terms.

The relevance to education of emotion terms such as these and other verbal aspects of emotion is easy to demonstrate, although the area is a complex one. Persistent activation of positive (e.g., pride) or negative (e.g., disappointed) emotion terms in the context of school will affect students' attitudes toward school and various actions that depend on students' emotional responses to school (e.g., attending classes, studying). Moreover, if school-related terms form an associative structure, as we have suggested, positive or negative experiences with one component of the network could spread to other components. A particularly good experience with a specific teacher, for example, could have widespread consequences for many elements in the school-related semantic network. Verbal processes are also involved in student and teacher self-talk related to emotion. Positive self-statements (e.g., I should try harder, Good work) are motivating and promote student persistence (Chapin and Dyck, 1976), and the cognitive or worry components of anxiety (e.g., I cannot do this; What if I fail?) are probably verbal (Schwartz *et al.*, 1978). Negative self-statements also contribute to dysfunctional cognitive processing in test-anxious students (e.g., Benjamin *et al.*, 1981; Bruch *et al.*, 1986) and play a central role in students with poor academic self-concepts. On the positive side, appropriate self-talk has been used in cognitive behavior-modification techniques to reduce test anxiety (e.g., Don't worry, Relax) (Craighead *et al.*, 1976), and it contributes to positive academic self-concepts.

The preceding examples demonstrate that DCT provides a useful framework for thinking about the role of emotion in education, but barely scratches the surface of an immense topic. Student and teacher emotions serve as both predictor and criterion variables in education. As predictors, student attitudes, interests, motivation, expectations, self-concepts, and anxiety contribute to school attendance, course selection, and achievement (e.g., Gauld and Hukins, 1980; Hembree, 1988; Rumberger, 1987; Schibeci and McGaw, 1981; Vollmer, 1984). On the teaching side, interests and motivation determine who enters teaching (Jackson, 1977). Teachers also have attitudes toward such educational topics as mainstreaming (Guerin, 1979), and they have anxieties about teaching such subjects as science (Coates and Thoresen, 1976; Westerback and Primavera, 1988). Moreover, teachers' attitudes about courses contribute to student achievement (e.g., Moore, 1988). With respect to emotions as criterion or output variables, affective constructs have a central place in several taxonomies of educational objectives (e.g., Gagne, 1977; McAshan, 1974), and are influenced by a variety of educational variables, such as school quality (Sosniak and Ethington, 1989), courses (e.g., science — Gauld and Hukins, 1980; Schibeci, 1984; Schibeci and McGaw, 1981), and specific teaching methods (e.g., mastery learning — Block and Tierney, 1974). Education programs similarly attempt to modify attitudes of education students (e.g., Yee, 1969).

Despite the substantial evidence that student attitudes and other emotional constructs are of great educational importance, teachers may lack the theoretical tools to deal with affective topics in a systematic way. Science teachers, for example, rate attitudinal objectives as less important than cognitive objectives, do not systematically measure attitudes, and believe that attitudes cannot be changed (Schibeci, 1981). One strength of DCT is that the same constructs that explain cognitive phenomena can be used to build concrete models of the verbal and imagery mechanisms that underlie student and teacher affect, and its modification. This unified approach to cognition and emotion may help teachers to better understand emotional phenomena and to achieve affective goals in their classrooms. The same mechanisms can also be applied to other noncognitive domains, such as motor skills.

Motor Skills and Education

By now readers will anticipate (correctly) that DCT conceptualizes motor skills in terms of images for perceptual patterns and movements, relevant verbal codes, and associative and referential processes that govern activation of the interconnected codes; that is, motor skills involve the same basic mechanisms that account for cognition and affect. Nonverbal components of the motor system include both kinesthetic and visual images. Kinesthetic imagery refers to the "feel" of the action from an internal perspective. Examples are what it feels like to print or type particular letters and numbers, to pour a beaker of liquid into a test tube, to play a musical instrument, or to articulate a unique sound in a foreign language. Visual imagery refers to the appearance of actions from the perspective of an external viewer; for example, what the preceding actions would look like if another person (or yourself) performed the action. There are many theoretical links between imagery and motor skills, both past and present. Historically, for example, Piaget equated imagery with internalized imitation. More recently, Paivio (1971) has emphasized the role of motor components in transformational imagery, and the imagery system in DCT has counterparts in the nonverbal components of other theories for skilled movement (e.g., Bandura, 1969; Shallice, 1978). Motor schema, for example are hypothesized to represent response parameters and sensory consequences of movement, presumably in a nonverbal form (Schmidt, 1975).

Empirically, research has demonstrated a number of important relations between action, imagery, and other cognitive phenomena (e.g., Engelkamp, 1990). One sort of evidence for concrete imaginal codes comes from modality-specific interference and priming effects. Klatzky *et al.* (1989), for example, found that priming a specific motor action (e.g., clenching the hand) in undergraduates facilitated subsequent judgments for statements about actions related to the prime (e.g., crumple a newspaper), whereas verbal primes (e.g., saying "clench") did not produce priming. A close relation between motor and imagery processing is further supported by evidence that individual differences in imagery ability correlate positively with performance on experimental motor tasks. Across 219 subjects ranging from 10–40 years of age, for example, Goss *et al.* (1986) found that novel movements of the hand were learned more easily by people with good visual and kinesthetic imagery than by people with poor imagery ability. Other research suggests that visual imagery ability contributes more to early stages of learning, whereas kinesthetic imagery ability contributes to later stages (Fleishman and Rich, 1963). The central role of imagery in movement is also consistent with the widespread use of imagery methods by sports psychologists (Paivio, 1985; Suinn, 1983; Weinberg, 1982). In a comprehensive review of research on the benefits of mental rehearsal for teaching motor skills, Feltz and Landers (1983) concluded that imaginal practice improves performance relative to a control group, especially for motor skills with cognitive components.

With respect to the role of imagery in motor skills, there are many potential educational benefits of experimental research and relevant theories, such as DCT. The work on mental rehearsal of motor skills suggests that students can use mental imagery to perform and practice new actions. Children learning to print letters, for example, might be instructed to think of a picture for each letter before starting to draw, or to mentally practice printing between actual printing sessions. Although none of the 60 mental rehearsal studies reviewed by Feltz and Landers involved an academic motor skill, educators have considered the role of images in motor skills and used remedial techniques that involve imaginal processes. Mercer and Mercer (1981, p. 348), for example, attributed shape and size errors in printing to incorrect mental images and described fading techniques that involved copying or tracing models that were gradually faded out (p. 355; see also Sisson *et al.*, 1988). Theoretically, such fading methods should foster the generation of images as models prior to action, a strategy that was suggested by Thomassen and Teulings (1983, p. 195). Imagery mnemonics can also be used to facilitate perceptual and motor learning of letter shapes and other novel patterns. One mnemonic method relates the shape of letters to images for familiar objects that begin with the sound of the letter (see Clark and Paivio, 1987). The letter *f*, for example, can be mentally imaged as a flower with leaves at the cross-bar and a blossom at its head. This mental image serves as a visual pattern for decoding and producing the letter, and as a mnemonic for its sound.

Verbal processes also contribute to the DCT view of motor skills, including such verbal representations as names for specific acts (e.g., push, grasp, and other action labels), words for general qualities of acts (e.g., slowly, soft), and names for particular patterns that movements can produce (e.g., curve, vertical line, circle). Moreover, all words inherently involve motor skills, inasmuch as words are spoken, written by literate people, typed by those with keyboarding skills, and represented manually in sign language. Indeed, articulatory codes may form the basis for word representations, since speaking is generally acquired before reading. Verbal components or their abstract equivalents also appear in other theoretical models of movement (e.g., Bandura, 1969; Shallice, 1978).

Verbal and imaginal representations relevant to action appear to be organized in associative networks analogous to those seen in the cognitive and emotional domains. The priming studies of Klatzky and her colleagues (e.g., Klatzky *et al.*, 1989), for example, suggest that spreading activation is similar for motor and semantic representations. In addition, Klatzky *et al.* (1987) demonstrated that many hand actions could be placed into categories (e.g., push, poke) on the basis of dimensions for the typical stimuli involved in the action (e.g., pencil, stapler, doorknob, calculator key). The similarity between motor and semantic associative processes is also suggested by the robust effect of uncertainty in both domains. Just as picture-naming slows as the number of alternative labels increases (Paivio *et al.*, 1989), the speed of motor responses similarly decreases with uncertainty (e.g., Fitts and Switzer, 1962; Hyman, 1953). Motor skills and semantic retrieval also both involve inhibitory processes. Kornblum (1965), for example, used inhibition to explain the fact that responding with two different fingers on the same hand (e.g., typing *j* and *k* with the right index and middle fingers) is slower than responding with fingers on different hands (e.g., typing *j* and *d* with the right index and left middle fingers). Kornblum hypothesized that making one response involved suppressing other responses, and that it was easier to suppress a remote finger on the other hand than to suppress an adjacent finger on the same hand.

Associative structures in the motor domain often have a sequential component (Kimura and Archibald, 1974), which may be associated particularly with verbal aspect of movement. Fischman *et al.* (1981), for example, note that serial motor tasks (e.g., a gymnastics routine) have a larger verbal component than do continuous motor acts (e.g., tracking a baseball or football). Verbal tasks also disrupt performance of such sequential acts as tapping, especially for the right hand (Lewis and Christiansen, 1989). This relation between verbalization and sequential motor tasks is consistent with the DCT assumption that language is specialized for sequential processing (Paivio, 1971, 1986).

These verbal and related associative processes are highly relevant to teaching. Deaf children, for example, demonstrate a delay in their drawing abilities relative to hearing children, perhaps because of language-related difficulties (Ewing, 1957, cited in Lawton, 1968). Verbal labeling of action components are also used to teach new motor sequences, especially during the initial description and mental rehearsal of new skills. Printing the letter *a*, for example, might be guided by such self-commands as "draw a circle touching the line" and "draw a straight line that touches the circle's right side." The associative differences between within-hand and between-hand actions suggest that teachers of music, typing, and related motor skills should anticipate particular problems with within-hand sequences, might instruct students to practice them more often, and could develop special exercises or feedback to enhance suppression of interfering responses on the same hand.

The DCT view of motor skills and associated research have numerous other applications in education. Motor skills are involved in many regular classroom activities, such as printing and writing, articulation of speech sounds, typing, physical education, art and music, and manual skills involved in the use of equipment in vocational and laboratory classes (e.g., Brown & Atkins, 1988, p. 91; Kirschner and Meester, 1988). With respect to special education, some school-related dysfunctions are primarily motoric (e.g., stuttering, illegible writing). Moreover, one consequence of mainstreaming may be that teachers will have to teach increasingly heterogeneous motor skills, since the mentally retarded and other special populations can require instruction in dressing, brushing their teeth, cooking, and other adaptive motor skills (Robinson and Robinson, 1976).

Motor skills are also relevant to research on individual differences and associated work on the prediction of early school success. Some studies have concluded that measures of motor skill are relatively independent of measures of intelligence (e.g., Terrasi and Airasian, 1989), but other work suggests some correspondence between the two domains. Jensen (1987) and others, for example, report that people with higher scores on intelligence tests respond more quickly on choice reaction time tasks and are less affected by increases in uncertainty than are people with lower intelligence. The DCT view that common mechanisms (e.g., imagery, verbal associations, inhibition) underlie motor and cognitive domains could help to explain their correlation. Motor skills are also used as predictors of later academic achievement (e.g., Belka and Williams, 1979; Butler *et al.*, 1982), which explains the interest of early educational researchers in children's drawing skills (e.g., Childs, 1915). Motor skills are major components of the McCarthy scales and other contemporary tests of ability and school readiness in young children. Simner (1989) has developed a test that predicts subsequent academic performance from the frequency of form errors in copying letters and numbers (i.e., errors that involve addition, deletion, or misalignment of parts, such as copying F as E or 2 as Z). Form error scores of 16 or more in preschool, for example, identify over 70% of the students who will have academic difficulties at the end of first grade. Particular motor disturbances are also sometimes found in children with speech and language disorders, again suggesting a close relation between the verbal and motor domains (e.g., Cromer, 1983; Noterdaeme *et al.*, 1988).

To conclude this section, DCT provides theoretical mechanisms that are useful in understanding such noncognitive domains as emotion and motor skills. Images, verbal representations, and associative and referential processes are implicated in many experimental studies of emotion and motor skills, and permit the development of specific models relevant to a wide variety of educational topics (e.g., achievement motivation, mental rehearsal of motor skills).

THE SCIENCE AND PRACTICE OF EDUCATIONAL PSYCHOLOGY

A comprehensive theory of education must explain not only the psychology of students and teachers, but also the psychological processes that underlie the science and practice of educational psychology. Here we demonstrate that DCT can further our understanding of the epistemological foundations of educational and psychological research, and also has much to say about such practice issues as teacher education.

DCT and the Science of Educational Psychology

A fundamental question about educational psychology concerns the epistemological foundations for its standing as a science. Traditional approaches to educational and psychological research acknowledge the necessity of empirical testing of tentative hypotheses, and the greater certainty of observation terms relative to theoretical terms. These traditional views of science are reflected in educational psychology texts, which tend to endorse empirical approaches to knowledge, justify their conclusions by empirical research, and base educational research methods on the distinction between observation and theory (e.g., Ash and Love-Clark, 1985). Moreover, educational researchers in several areas have explicitly contrasted constructs at the observational and theoretical levels. Researchers who study teaching, for example, make a distinction between low- and high-inference behaviors, such as "uses outlines" vs. "is organized" (e.g., Murray, 1983a,b; Rosenshine and Furst, 1971).

In recent decades, some educators have questioned this norm of objectivity in empirical social science (Westkott, 1979), and have become disenchanted "with the underlying assumptions and the methods of traditional social science approaches" (Heshusias, 1988, p. 62). Such challenges are often based on philosophical analyses of science that give decreased weight to empirical factors because data are themselves thought to be "theory-laden" (e.g., Brown, 1977; Kuhn, 1962). Criticisms of present approaches to social science often include recommendations for a shift to less empirical research methods in education and related disciplines (e.g., Bloland, 1989; Eastwood, 1988). Similar criticisms of empirical approaches to knowledge are found in psychology (e.g., Koch, 1981; Royce, 1982) and science education (e.g., Hodson, 1985). Finley (1983), for example, states that current science programs give too much emphasis to observation, laboratory activities, and other empirical practices. He proposes that science education be based instead on less empirical philosophies of science.

DCT provides a well-founded perspective on these challenges to the traditional epistemological foundations of educational psychology and related disciplines. Despite the criticisms and some complex issues (see Clark and Paivio, 1989a; Paivio, 1986), the empiricist separation of observation and theory is consistent with the DCT distinction between concrete and abstract terms, and we have already seen that concreteness has robust effects on comprehension, meaning, the structure of knowledge, and other attributes relevant to scientific discourse. To generalize the natural language results to scientific terms, Clark and Paivio (1989a) had independent groups of psychologists rate the observability and concreteness of 72 psychological terms on 7-point scales. High ratings on observability, for example, were to be given to terms designating observable entities and whose meanings were based primarily on direct or instrument-mediated activation of the senses. Mean ratings were calculated for each term, and across the 72 terms, observability and concreteness correlated .89, suggesting that the two ratings measure a common construct. Sample terms (and their mean observational ratings) are: image (2.11), schema(ta) (2.33), attribution (2.89), anxiety (3.78), intelligence (3.78), comprehension (4.11), peer group (4.89), reward (5.67), recall (6.00), crying (6.33), and heart rate (7.00). In a subsequent task Clark and Paivio measured graduate students' reaction times to generate images or verbal associations for the items. Observability correlated -.52 with imagery reaction times for the items and .65 with the frequency of spontaneous imagery in the verbal association task, as indicated on postexperimental questionnaires. These results demonstrate that the observability (i.e., concreteness) of scientific terms can be measured in reliable and valid ways, contrary to philosophical assertions that the distinction lacks a clear basis.

To evaluate whether observational terms enjoy the benefits claimed for them by empirical views of science (e.g., greater intersubjective agreement), we had academic psychologists independently rate the terms for their consistency and distinctiveness of meanings. Terms rated high on consistency were to have stable and reliable meanings that would not vary from one person or time to another. Mean observability (and concreteness) correlated very highly with mean ratings for consistency (.81) and distinctiveness (.78) of meaning. Such results demonstrate that observable psychological terms are more likely to mean the same thing to different researchers than are theoretical terms, which weakens the idea that observational and theoretical terms are equally theory-laden. The study also demonstrates that epistemological issues are amenable to empirical investigation and that researchers in psychology and education need not depend entirely on philosophers of science for the foundations of their disciplines.

Such findings support traditional empirical approaches to science and educational research. Moreover, this work and other research on scientific language and thought will eventually permit the development of a well-founded cognitive theory for educational psychology as an empirical science. Empirical and theoretical considerations suggest that the DCT constructs of concreteness and imagery (cf. Paivio, 1983a) will emerge as important elements in models of science, and will have important consequences for the science of educational psychology and for its practice.

DCT and Teacher Education

The practice side of educational psychology includes its major role in teacher education. Pedagogical aspects of educational psychology courses and texts can be conceptualized in terms of the DCT constructs of concreteness, imagery, and verbal associative processes. Indeed, everything that we have discussed in this article about the structure of knowledge, effective instruction, individual differences, and so on is relevant to educational psychology as a subject in teacher education and other university programs. However, we will concentrate on some special phenomena relevant to concreteness and imagery effects.

The importance of concreteness and imagery in DCT raises the question of the relative concreteness of educational psychology, the use of imagery, and the relation between concrete and abstract concepts. Although empirical data are presently inadequate to permit strong conclusions, there are some indications that educational psychology may be overly abstract and theoretical, or may not connect theory and practice as strongly as possible. In discussing theories in educational psychology, for example, Brophy (1979, p. 738) criticized the "overly abstract and grandiose theories that have plagued the field to date." An educational psychology course studied by Donald (1986) also emphasized abstract concepts, likening the course more to philosophy than to science (see also Goldschmid, 1967).

Evidence that educational psychology may emphasize the theoretical and abstract, rather than concrete phenomena, also comes from observations that data are seldom presented in educational psychology texts. We examined the percent of pages in four contemporary educational psychology texts that actually presented data in a table or a figure. The mean percent was only 3.69%, with one text presenting actual data on only 6 of 842 pages. Although a lack of data in tables and figures might be compensated for by detailed verbal descriptions of the results of studies, the limited presentation of data suggests a possible underemphasis of concrete phenomena. The shortage of data is particularly striking when one considers that, over 60 years ago, Starch (1928) wrote an educational psychology text that contained figures or tables on 43.1% of its 536 pages. Moreover, Starch (1930) provided a manual of laboratory research activities relevant to education. If concrete phenomena provide the conceptual pegs on which more abstract theoretical ideas are hung, then Starch's emphasis on facts and concrete research activities seems well-motivated.

Textbooks are only one way that information is transmitted, but other aspects of teacher education lead to some concern about the extent to which concrete data and research methods are discussed and related to theory. Champion (1984) observed that education faculty often mention but less often model or demonstrate research practices in their courses, again suggesting an overly abstract approach to educational research and theory. This lack of emphasis on research activities and data may occur because education faculty tend to be more committed to teaching and practice than to research (Nystrom *et al.*, 1984; Stark *et al.*, 1986; Troyer, 1986). Perhaps these and related phenomena contribute to the historical gap that has existed between educational research and practice (e.g., Clifford, 1973; Resnick, 1981), despite the extensive research literature available on many educational topics.

Another potential source of concrete experiences to which abstract theories can be tied is the classroom. Data once again do not permit strong conclusions about the extent to which theory and actual classroom experiences are linked, but several studies suggest that instructional theory and its relation to practice are seldom the focus of supervisor conferences with education students. In her review, Kagan (1988, p. 9) concluded that supervisors "almost exclusively discussed narrow, particularistic concerns rather than attempting to embed immediate problems in larger theoretical contexts." This finding suggests that teacher education students are not being explicitly shown how to relate educational theories to their classroom practices, nor receiving feedback that would strengthen the cognitive processes that underlie translation between abstract theory and concrete experience.

Another way in which abstract theories can be concretized is through the development of mechanistic models for educational phenomena. We have seen that images of nonverbal objects or events, verbal associative links, and other DCT constructs permit the development of concrete, mechanistic models in diverse areas relevant to education. For example, activation of the imagery system can explain the instructional benefits of concrete examples, and converging activation of shared verbal associations can explain the effects of organization on memory for text. Research on the benefits of concrete mental models for comprehension and generalization of principles (Mayer, 1989) suggests that these mechanistic models provided by DCT could make the case for certain practices more compelling to teachers and could lead to more sophisticated application of the techniques. If concrete examples function by eliciting imagery, for example, teachers who understand that principle may be more aware of students who lack the experiences necessary to construct such images, or who need their imagery abilities strengthened.

As emphasized throughout this article, education depends on a complex and subtle interplay between course content, individual differences, and instructional factors. If theory and research support the preceding arguments that educational psychology could be more concrete and that phenomena and abstract theory need stronger connections, effecting these changes will require considerable sensitivity and empirical knowledge about education students and faculty. Education students, for example, may not be predisposed to think about education scientifically, inasmuch as their interest and personality patterns are distinct from those of science students (e.g., Goldschmid, 1967; Jackson, 1977) and their academic aptitudes may be lower than students in science and other select groups (Weaver, 1983), although the findings on ability are controversial (Clark, 1989). In addition to general aptitude, specific individual differences (e.g., imagery ability) are relevant to certain aspects of thinking scientifically about education, such as interpreting graphs and conceptual models, and quantitative research methods. Moreover, we have already noted that interests of education faculty may be somewhat incompatible with a research emphasis. Current research on the thought processes of teachers and education students will provide more information relevant to these questions.

In this section, we have shown that DCT and associated empirical findings are relevant to both the science and the practice of educational psychology. Concreteness effects in natural and scientific languages are consistent with the special epistemological status of observational events and terms, and with traditional approaches to educational research. With respect to practice, DCT and research on the benefits of concreteness and imagery suggest that teacher education might benefit from greater emphasis on concrete phenomena and models. Much research will be required, however, to determine the validity of these claims and how best to act on them.

GENERAL DISCUSSION

We have demonstrated that an integrated set of DCT principles accommodates cognitive, affective, and sensorimotor phenomena of interest to teachers and educational psychologists. Moreover, DCT and related research suggest possible roles for concreteness and imagery in the science and practice of educational psychology itself. In this general discussion, we return to the question of DCT and molar theories for educational phenomena, describe some general benefits of a unified DCT approach to education, and briefly note some unresolved challenges.

Compatible with Higher Levels of Explanation

DCT accommodates both basic associative phenomena and such higher-order cognitive processes as strategies, expectations, decisions, and attributions. Molar explanatory constructs are paradigmatic features of contemporary educational and cognitive psychology, underlying many educational models and much research on cognitive process instruction. Indeed a strategy orientation is the dominant approach to understanding and teaching comprehension, writing, learning, memory, thinking, problem-solving, and other general cognitive skills (e.g., Pressley *et al.* 1989a,c). Strategy or process approaches are also advocated for teaching science (e.g., Gagne, 1966; Reif and Heller, 1982) and other specific school subjects, for promoting affective change, and for enhancing motor skills learning.

DCT incorporates strategies and related theoretical constructs within the general associative framework described in this article, with verbal processes playing a central role at the present time. The importance of language in strategic thinking is consistent with much research and theory on self-regulation and cognitive process instruction. Early work by Luria (1961) demonstrated that verbal self-instructions were a fundamental basis for self-control, and cognitive modification methods continue to emphasize self-talk (e.g., Meichenbaum, 1976). Despite the importance of verbal processes, however, strategies and associated knowledge can also be represented imaginally. Spatial networks, for example, can be used to represent an associative hierarchy of different strategies (e.g., Dansereau *et al.*, 1979); some strategies might be represented imaginally rather than verbally (e.g., drawing circles freehand using a cookie-cutter in one practice task described by Pressley *et al.*, 1985); and affective information stored about strategies (e.g., their positive or negative valence) could be nonverbal.

To illustrate the DCT approach, consider a single strategy in which an impulsive boy learns to say to himself, "Stop and think," before acting (e.g., Meichenbaum, 1976). A DCT model for the effects of this treatment will describe the verbal representation of the "stop and think" instruction, how it is evoked by various verbal and nonverbal stimulus patterns (e.g., teacher asking a question, doing seat work, specific verbal prompts), and how it moderates subsequent cognitive processing by the student (e.g., inhibiting impulsive reactions). An explanation at this mechanistic level will necessarily involve associative mechanisms, including the inhibition that was discussed in the context of cognition and motor skills. It is already recognized that inhibitory mechanisms play important roles in the metacognitive processes that underlie self-regulation (e.g., Maccoby, 1980). That is, such self-instructions as "Stop and think," "Don't use rote rehearsal," or "Pay attention to my work" entail suppression of the specific cognitive, affective, or motor actions. Moreover, activation (i.e., choice) of one class of cognitive operation generally involves inhibition of competing operations, especially when those competing responses are the more familiar and habitual reaction of students. Generating mental images, for example, may require the suppression of rote repetition strategies that students have used in the past.

In addition to explaining single strategies, DCT provides a framework by which to represent more elaborate and sophisticated theories of metacognition, such as the Pressley *et al.* (1985) model for metamemory about strategies (see their Fig. 1). From a DCT perspective, expert strategy users would have verbal labels for the various strategies (e.g., SQ3R, keyword, imagery), and these verbal labels could be organized as an associative hierarchy in which similar strategies are clustered into superordinate categories (e.g., rehearsal, elaboration, and other classes). The entire network could be subsumed under a general label such as memory strategies or methods, and might be represented imaginally as a cognitive map. Each strategy label would be associated with mental representations that controlled the sequence of acts necessary to implement the strategy. The keyword strategy, for example, might be represented by a linked sequence of phrases such as, "generate similar sounding keyword" and "construct interactive image." Moreover, a verbal associative network could instantiate other knowledge about specific strategies, such as the situations under which they work (e.g., learning strange words) and evaluative information (e.g., works well). As in most domains, students would differ from one another with respect to the scope and organization of their strategy network because of different experiences (e.g., differential teaching of strategies) and differences in their capacity to benefit from experience (e.g., the use of mental imagery to store strategy information).

Educational and cognitive researchers have become increasingly skilled at eliciting knowledge from both expert and novice cognitive processors, and much empirical data on the verbal and nonverbal elements of student and teacher strategies is now being accumulated. Although we cannot yet instantiate all sophisticated strategies in terms of basic DCT mechanisms, we believe that all higher-level constructs, even those related to abstract metamemory acquisition procedures (Pressley *et al.*, 1985), must ultimately be reducible to primitive associative mechanisms. Stated another way, strategies, expectations, and similar high-level constructs are represented by the brain somehow and mediated by mechanistic processes that are fundamentally associative in nature. This does not deny the importance of strategies and deliberate behavior in explaining student and teacher behavior, but simply acknowledges that ultimately a nonstrategic level of explanation must be achieved. The higher-level models are necessary both as guides for practice and also to direct researchers as they piece together the complex network of basic mechanisms that underlie strategies and other higher-level phenomena. For their part, lower-level mechanisms concretize abstract theories about mental processes; permit more precise prediction and control of those processes and their effects; and, as we have tried to show in this article, provide unified explanations for diverse phenomena. In short, top-down and bottom-up approaches to educational research strengthen one another and are mutually dependent, and DCT is well-suited to this cooperative approach.

An Integrated Theory

The particular strength of DCT that we have tried to emphasize in this article is its unified approach to psychological phenomena relevant to education. Integrated theories overcome a major barrier to the development of sound scientific foundations for educational practices, namely the complexity of human behavior and the seemingly fragmented nature of much psychological research and theory. Piecemeal views of education complicate the learning and application of psychological principles because, as we have seen in this article, educators must consider many facets of human behavior, and each of the domains is very complex. It is impossible for educational psychologists and teachers to become masters of all these areas without some unifying theoretical framework. Moreover, applied researchers and practitioners must deal with people as whole units and do not have the luxury of neatly dividing human behavior into pure cognitive and affective components. Some of the disenchantment with basic psychological research expressed by applied researchers and practitioners may result from the disjointed nature of psychology and from domain-specific theories.

We can only speculate about the psychological mechanisms that underlie such fragmentation because our understanding of scientific and other scholarly behaviors is itself incomplete. One contributing factor, however, may be a tendency to use abstract constructs to explain psychological phenomena rather than considering basic underlying mechanisms. Different labels for abstract constructs imply distinct theoretical constructs, but the differences between tasks, phenomena, and processes may be superficial and mask common underlying mechanisms. As shown in this article, consideration of the concrete mechanisms that underlie task performance can reveal commonalities among quite diverse tasks and nominally distinct processes. Clark and Paivio (1984) similarly demonstrated that convergent associative mechanisms can explain behavior in diverse cognitive tasks.

The present article does not reflect the full potential of DCT for integration of educational topics because we have not examined specific features of individual school subjects and particular topics, such as special education. Each of these domains entails sophisticated psychological processes and models that can be captured within the DCT framework. We have briefly alluded to DCT research and theory relevant to specialized topics, but these need considerable elaboration. English literature benefits from research on figurative language (Katz *et al.*, 1988), mathematics from research on number processing (Clark and Campbell, in press) and gender differences in imagery ability, science from research and theory on the nature of scientific language and thought (Clark and Paivio, 1989a), physical education from research on motor skills learning (Paivio, 1985), and guidance counseling from the role of imagery in anxiety and other school-related moods. With respect to special education, nonverbal methods have been used to enhance learning of syntax in deaf children (Strφmnes and Iivonen, 1985), and DCT can explain various phenomena associated with the use of Blissymbols to teach language to cerebral palsied and other children with severe language dysfunctions (Yovetich and Paivio, 1981). In these examples, DCT provides a unified perspective on specific and diverse educational phenomena; but these and many other topics have not yset been explored fully.

Theoretical Challenges to DCT

This article has emphasized the positive contributions of DCT as a general perspective on educational and psychological phenomena, but many of the topics that we have discussed involve controversial empirical and theoretical issues that remain unresolved. As noted earlier, for example, concrete sentences do not always demonstrate more integration than abstract sentences on memory tasks, and use of concrete examples in lectures does not always correlate with learning. Such findings only weakly challenge the basic premises of DCT, however, because of our incomplete understanding of the role of nonverbal and verbal processes in many tasks. We have tried to show that deeper theoretical and empirical analysis of sentence memory and other tasks permits a reconciliation of the data and DCT. Deeper analysis includes consideration of item attributes, individual differences, and instructions, and the joint contribution of imagery and verbal processes to psychological phenomena.

In addition to specific challenges, some basic assumptions of DCT remain controversial. The DCT assumption of specific mental codes contrasts with the view that written and spoken words, images, and other forms of a concept elicit a common amodal representation of its abstract meaning. In DCT, semantically equivalent words (e.g., "book," "text," and "livre") and their corresponding objects are encoded by distinct verbal and imaginal representations that do not converge on a single, generic, abstract code. A shared image may exist for different concrete words, but not some unitary and abstract meaning code (Clark, 1978; Paivio and Desrochers, 1980). This issue is complex, and we just note here that DCT excludes inferred abstract codes because of much evidence for the importance of modality-specific representations in human cognition (see Paivio, 1983b), and because specific imaginal and verbal codes can explain findings used to justify the notion of abstract codes. Clark (1987), for example, argued that the DCT assumption of referential connections between verbal and imagery systems can explain the processing of sentences with embedded pictures (cf., Potter *et al.*, 1986), without the mediating abstract code that Potter *et al.* proposed. Moreover, evidence for the benefits of concrete psychological terms (see earlier review and Clark and Paivio, 1989a) makes us wary of excessive abstraction in psychological (and educational) theory.

DCT's empirical nature and theoretical flexibility have also been criticized for promoting *ad hoc* explanations (e.g., Potter and Kroll, 1987). But we think that the associative complexity of DCT and its probabilistic mechanisms are well-suited to the richness and variability of human behavior, which tend to be oversimplified in more formal models. In addition, the empirical approach of DCT to basic underlying mechanisms (e.g., research on the effects of concreteness on image generation) has produced elegant explanations for diverse phenomena, as we have tried to demonstrate using examples from both experimental and educational psychology.

In conclusion, the basic mechanisms of DCT permit unified explanations for a wide variety of educational phenomena, although unresolved issues remain. We have seen that concreteness, imagery, and verbal associative mechanisms lead to concrete models for specific phenomena in many areas of education and at many levels: comprehension, learning and memory, effective instruction, educational assessment, affect, motor skills, and the science and practice of educational psychology. The successful applications of the theory and its ability to accommodate strategic processes increase our confidence that the interconnected verbal and imaginal representations of DCT provide powerful mechanisms with which to approach the understanding of human behavior and experience. A coherent and unified set of principles provides detailed and specific explanations for quite diverse phenomena; consequently, DCT can help to integrate the complex field of educational psychology and to advance the science and practice of education.

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