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Concepts in Developmental Theories of Reading Skill: Cognitive Resources, Automaticity, and Modularity

KEITH E. STANOVICH

Oakland University

The concept of limited cognitive resources loomed large in reading theory for a considerable period, largely due to the impact of LaBerge and Samuels' influential automaticity theory. However, experiments that attempted to trace the development of automatic word recognition processes generated empirical paradoxes because the different criteria employed to operationalize the automaticity concept did not display convergent validity. For example, the development of obligatory processing did not completely coincide with the development of capacity-free processing. Recently, developmental reading theories have deemphasized the capacity component of the automaticity concept and have focused on another property: information encapsulation. The latter property is the centerpiece of the concept of modularity in cognitive science, a theoretical notion only partially overlapping with automaticity. Most current conceptions of the development of reading skill emphasize issues of the quality of lexical representations and information encapsulation—conceptions thought to be more empirically tractable than resource notions, given the history of methodological and theoretical complications involving the latter.

Most major concepts that are used in current reading theory can be traced back to Huey's (1908/1968) classic work, and the concepts of cognitive capacity and automaticity are no exception:

> Perceiving being an act, it is, like all other things that we do, performed more easily with each repetition of the act. To perceive an entirely new word or other combination of strokes requires considerable time, close attention, and it is likely to be imperfectly done, just as when we attempt some new combination of movements, some new trick in the gymnasium or new 'serve' at tennis. In either case, repetition progressively frees the mind from attention to details, makes facile the total act, shortens the time, and reduces the extent to which consciousness must concern itself with the process. (p. 104)

As many histories of the study of reading have noted (Venezky, 1977), after Huey there was darkness—the behaviorist era led to a decrease in the type of cognitive theorizing about the reading process evident throughout Huey's work. Vague notions about cognitive capacity occasionally sputtered through the educational literature, but theorizing about the reading process in the manner of Huey was rare. Like many other

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information processing concepts, limit-resource theories were resurrected shortly after the cognitive revolution.

Here, we will trace the postbehaviorist era history of the limited-resource concept in theories of reading acquisition. Its resurgence and subsequent popularity were largely due to the influence of the automaticity theory of reading developed by LaBerge and Samuels (1974). Eventually, however, conceptual and empirical weaknesses in the automaticity concept as an explanatory construct in developmental reading theory were revealed. These problems arose at a time when the concept of modularity was being elaborated within cognitive science. Aspects of the modularity concept, such as information encapsulation, have the potential to account for some of the same developmental trends in reading performance that resource theory had explained. As a result, current reading theories have emphasized questions of representation quality and the nature of information exchange among semiautonomous process. The future of the resource concept in reading theory remains uncertain.

AUTOMATICITY THEORY: LABERGE AND SAMUELS

It was not until the classic paper by LaBerge and Samuels (1974) that ideas about cognitive capacity and resource use in the modern information processing sense were thoroughly reintegrated with reading theory. At the very beginning of their paper, LaBerge and Samuels (1974) outlined the basic limited-capacity argument that was accepted, either explicitly or implicitly, by reading researchers throughout most of the subsequent decade:

> During the execution of a complex skill, it is necessary to coordinate many component processes within a very short period of time. If each component process requires attention, performance of the complex skill will be impossible, because the capacity of attention will be exceeded. But if enough of the components and their coordinations can be processed automatically, then the loads on attention will be within tolerable limits and the skill can be successfully performed. Therefore, one of the prime issues in the study of a complex skill such as reading is to determine how the processing of component subskills becomes automatic. (p. 293)

There were several assumptions in Laberge and Samuels' treatment that became canonical for many reading researchers. First, their theory assumed a strong demarcation between word recognition processes and all postlexical processing, because it was assumed that most, if not all, postlexical comprehension processes would be resource-demanding and probably would not be good candidates for the development of acquired automaticity (in general—see Perfetti, 1985, pp. 102–106; Perfetti & Curtis, 1986). Most demonstrations of acquired automaticity thus focused on prelexical processes such as feature extraction, orthographic segmentation, and phonological coding. The examples in the classic LaBerge and

Samuels paper were all of this type. Few assumptions about how capacity was allocated postlexically were made. Instead, it was merely assumed that whatever the distribution of postlexical capacity allocation, the key to optimal processing at this level was the reallocation of unneeded capacity from lower levels via the acquired automaticity of lexical access. Much subsequent theorizing in reading—such as Perfetti's (1985; Perfetti & Lesgold, 1977, 1979) influential verbal efficiency theory—contained variants of these assumptions.

Resource and Automaticity Models of Reading Acquisition

It will be noted that in emphasizing the concept of automaticity LaBerge and Samuels (1974) focused the attention of reading researchers on the flip-side of the processing resource question: namely, on processes that are executed without depleting cognitive resources. In short, "the process of automatization was viewed as a gradual withdrawal of attentional involvement in performance" (Logan, 1985, p. 375). As Kahneman and Treisman (1984) have emphasized: "The study of attention underwent a significant paradigm shift during the decade of the 1970s, almost a reversal of figure and ground: the null hypothesis for research was inverted as the focus of interest moved from the nature of attention limits to the exploration of automatic processing" (pp. 29–30). This bias toward a focus on the degree of automaticity rather than on the direct assessment of resource use was also characteristic of the history of these concepts in the reading domain.

Interestingly, however, when LaBerge and Samuels (1974) attempted to operationalize their concept of automatic processing, they chose not to tackle directly the measurement problems inherent in assessing resource-free processing. Instead, they chose a correlated characteristic of capacity-free processing: obligatory execution—the tendency for an automatized process to execute regardless of where the conscious attention of the subject is directed. Specifically, they argued: "Our criterion for deciding when a skill or subskill is automatic is that it can complete its processing while attention is directed elsewhere" (p. 295).

This particular choice was to have important consequences for the subsequent history of the automaticity concept in reading theory. LaBerge and Samuels had implicitly equated the obligatory nature of an automatic process—its unconscious triggering and ballistic execution—with capacity-free processing. In addition, the use of processing resources was conflated with the idea of conscious attention, and conversely, lack of conscious attention was viewed as synonymous with resource-free processing. Only later was the necessity of theoretically separating the issues of obligatory execution, resource use, and conscious

attention fully recognized (Humphreys, 1985; Logan, 1985; Paap & Ogden, 1981).

The tendency to intertwine resource use with conscious attention in reading theory was reinforced by the popularity of Posner and Synder's (1975) two-process model of cognitive expectancies. Although this model was originally developed within the context of the tasks, methods, and conceptual apparatus of experimental psychology, it eventually had a strong influence on theories of reading acquisition when it became integrated with automaticity theory. Posner and Snyder (1975) also popularized the subsequently much-used priming methodology, whereby the subject is presented with a cue that predicts (probabilistically) a target stimulus. When the cue correctly predicts the target, response time to the latter is faster than a neutral baseline (a facilitation effect). However, when the cue incorrectly predicts the target, whether response time to the target will be slower (display an inhibition effect) depends importantly on certain conditions of the experiment.

Theoretically extrapolating from the results of a variety of these priming experiments, Posner and Snyder (1975) outlined the time course and facilitative/inhibitory patterns of two different expectancy mechanisms: one a capacity-draining conscious mechanism and the other a resource-free automatic priming mechanism. According to Posner and Snyder, the conscious attention mechanism caused an inhibition of unexpected signals as well as the facilitation of expected signals, the former because "the mechanisms of conscious attention are limited in capacity and the use of these mechanisms by one signal will have inhibitory consequences for other signals" (p. 670). The automatic spreading activation process, in contrast, was posited to facilitate expected signals but not to inhibit the processing of unexpected ones: "Activation of a pathway in the memory system facilitates the processing of signals related to it, but there is no widespread inhibitory consequence of such activation" (p. 670). Posner and Snyder's (1975) two-process model of expectancy was generalized to word recognition and single-word priming by Neely (1977) and to sentence processing situations in the empirical work of Stanovich and West (1979, 1981, 1983a; West & Stanovich, 1978).

In my interactive-compensatory model of individual differences in reading (Stanovich, 1980), I used the Posner–Snyder expectancy framework to explain a longstanding paradox in the reading literature. It had consistently been found that children who were poor comprehenders invariably had poor word recognition skills. Additionally, and unexpectedly, however, they tended to show large linguistic context effects in many tasks. It had traditionally been assumed in reading theory that poor readers would display markedly attenuated contextual sensitivity (e.g., Smith, 1971).

These seemingly paradoxical findings were resolved, first by showing, via a review of the literature (Stanovich, 1980), that the greater contextual facilitation shown by poorer readers was confined to word recognition tasks and did not extend to reading tasks involving comprehension. It was then proposed that the contextual facilitation of word recognition could result from either of the Posner–Snyder expectancy mechanisms. The automatic spreading activation mechanism would result in contextual facilitation with no costs to other aspects of performance. In contrast, if the attentional mechanism was employed, it would likewise facilitate word recognition performance, but at the cost of depleting the cognitive resources available to other simultaneously operating processes. The performance paradox was explained by positing that the severely deficient word recognition processes of the less-skilled readers caused them to rely on the conscious expectancy process because of the additional facilitation that it provided—but at the cost of further depleting the resources available to higher-level comprehension processes. Fluent readers, in contrast, had word recognition mechanisms that were so efficient that they did not necessitate the use of the attentional mechanism and thus did not incur the costs of its use. The net result was that the poorer reader devoted more resources to the local level of word recognition, relied more on contextual mechanisms, but simultaneously further stressed an already inefficient comprehension system.

Subsequent developments confirmed the broad outlines of the interactive-compensatory model, although specific disputes arose over whether the Posner–Snyder two-process theory was the best way to conceptualize expectancy mechanisms (see Becker, 1982, 1985; Briggs, Austin, & Underwood, 1984; Leu, DeGroff, & Simons, 1986; Pring & Snowling, 1986; Schwantes, 1985; Simons & Leu, 1987; Stanovich, 1986, in press a, b; Stanovich, Nathan, West, & Vala-Rossi, 1985; Stanovich & West, 1983a). During the same time period, Perfetti's (1985; Perfetti & Curtis, 1986; Perfetti & Lesgold, 1977, 1979) verbal efficiency theory was further developed and elaborated. This model shared many of the canonical assumptions of the LaBerge and Samuels (1974) automaticity theory, and conceptualized individual differences in much the same way as the interactive-compensatory model (see Perfetti, Goldman, & Hogaboam, 1979; Perfetti & Roth, 1981).

A DEVELOPMENTAL PARADOX

Ironically, however, during the very period when these resource-based models were gaining in popularity, the cognitive capacity notion as it applied to reading-related processes began to run into trouble. LaBerge and Samuels' original paper relied heavily on the catch-trial technique to demonstrate the properties of an automatic process. Generically, this

methodology involves surprising the subjects with a few "catch trials" interspersed randomly within a sequence of trials that have oriented the subject's attention to some other stimulus. When the catch-trial stimulus appears, the subject has to reorient attention to that stimulus and remember precisely what he/she had been instructed to do with it. This attentional reorientation presumably takes some finite amount of time. The key manipulation concerns the prior familiarity with the catch-trial stimuli. The assumption is that only if the catch-trial stimulus was automatized would processing take place during the attentional shift. Nonautomatized stimuli, in contrast, would have to wait for the attentional shift to be complete before processing of them could begin.

LaBerge and Samuels (1974) presented several examples of different sets of stimuli that were processed equivalently when given direct attention, but that resulted in differential performance (in favor of the familiar stimuli) when the attentional reorientation of the catch-trial procedure was required. Presumably, the performance difference between two such stimulus sets reflects the additional processing that takes place for the familiar (automatized) stimuli while attention is being switched. Additionally, LaBerge and Samuels demonstrated that the performance difference between such stimulus sets decreased as the nonautomatized set received more practice.

Our purpose here is not to attempt a full methodological review of the catch-trial procedure, but only to emphasize that it was designed specifically to operationalize one particular criterion for deciding when a skill or subskill is automatic: "that it can complete its processing while attention is directed elsewhere" (LaBerge & Samuels, 1974, p. 295). This particular operationalization—obligatory execution not demanding a conscious control process—was to have considerable influence on developmental work on the automaticity concept and on reading theory in general.

Probably because the procedure is not data-efficient and because it requires rather complex instructions, the catch-trial procedure has never been a popular method for assessing automatic stimulus recognition in studies of children. Instead, researchers turned quite naturally to the Stroop paradigm, which seems to straightforwardly operationalize the idea of stimulus processing while attention is directed elsewhere. In the generic Stroop paradigm (see Dyer, 1973; La Heij, 1988; Jensen & Rohwer, 1966) the subject must respond by naming a simple property of a stimulus (naming the color of a patch, the name of a line drawing, or the number of items in an array) while in close proximity is a verbal stimulus (e.g., written word) that conflicts with the required response (e.g., the word "blue" written on a red patch to which the subject must respond by saying "red"). Automatic word recognition is inferred by the lengthened response time in the conflict situation compared to the baseline situation

where there is no conflicting verbal stimulus. (Stroop effects can be explained by an output-interference theory [see Brainerd & Reyna, 1989], but such accounts have not figured prominently in the developmental reading literature.)

The interference caused by the conflicting written word becomes an index of automaticity via the argument that the Stroop task reflects the obligatory (indeed, unwanted) processing of the word even though the subject's attention is directed elsewhere. Actually, the Stroop task seems to be an extreme case of the "processing while attention is directed elsewhere" logic, because after several trials, most subjects not only are directing there attention "elsewhere" but are actively attempting (unsuccessfully) to *ignore* the written word.

By the early 1980s, however, experiments that had employed variants of the Stroop task with children and that had examined developmental and reading-skill trends had uncovered a puzzling theoretical problem. Numerous studies (e.g., Ehri & Wilce, 1979; Guttentag & Haith, 1978, 1980; Posnansky & Rayner, 1977; Schadler & Thissen, 1981; Stanovich, Cunningham, & West, 1981; West & Stanovich, 1978, 1979) had indicated that automatic word recognition developed remarkably early in a child's instructional history. At least for words of moderate to high frequency (most current accounts emphasize that it is stimuli, not processes, that become automatized, see Logan, 1988, Perfetti, in press), robust indications of automaticity were present by the middle of the first-grade year, and by second or third grade many Stroop indicators of automaticity were at asymptote. This finding was at odds with the general (although mainly untested) assumption that the development of prelexical automaticity was a mechanism that fueled comprehension increases for a long period of fluency acquisition.

DIFFERENTIATING COMPONENTS OF AUTOMATICITY

What the puzzling developmental findings actually indicated was that the idea of obligatory/intentionless processing and that of resource-free processing had been too easily conflated in discussions of the automaticity concept. Direct experimental evidence supporting such a criticism was contained in the work of Paap and Ogden (1981; Ogden, Martin, & Paap, 1980). These investigators employed the dual-task methodology that had been used by experimental psychologists to index the differential capacity used by various cognitive processes. Posner and Boies (1971) did some of the seminal work that demonstrated the utility of the technique. The methodology involves defining a primary task, the cognitive components of which are to be assessed for capacity usage. Subjects become practiced at completing the primary task while sometimes responding to a probe (or secondary task) that occurs on random trials during the execution of the

primary task. The probe is usually something like a white-noise tone to which the subject makes a single predetermined response, usually a button press. The reaction time to the probe becomes an index of the relative capacity usage of the primary-task processes occurring at the time of probe onset. The slower the reaction time to the probe (compared to a baseline where only the secondary task is being performed) the more cognitive capacity the overlapping process in the primary task is assumed to draw.

Paap and Ogden (1981) superimposed a probe task on the Posner–Snyder priming paradigm using letters as stimuli. Consistent with the Posner–Snyder idea of automatic priming, they found that a nonpredictive prime that the subjects were instructed to ignore still affected the processing of some subsequent stimuli, thus indicating obligatory processing of the letter. However, the ignored letters slowed the secondary probe relative to a baseline, indicating that basic letter encoding processes were not entirely free from capacity utilization, even though they displayed the characteristic of obligatory processing. Paap and Ogden (1981) concluded that "With respect to letter encoding, an automatic process is usually defined as a process that occurs without intention and without interfering with a concurrent secondary task . . . the most significant general conclusion that can be drawn from these experiments is that the criteria of obligatory processing and interference-free processing should be disassociated" (p. 518).

Results like those of Paap and Ogden (1981) made researchers reconsider the linkages assumed in the automaticity framework that had been outlined by LaBerge and Samuels. Subsequent work has reinforced the conclusion that the standard criteria for automaticity do not completely converge (see Humphreys, 1985; Kahneman & Chajczyk, 1983; Kahneman & Treisman, 1984; Logan, 1985; Zbrodoff & Logan, 1986). In particular, processes that are obligatory—in that they execute in the presence of the appropriate stimulus regardless of the direction of attention or of conscious intent—may still utilize cognitive resources. Thus, it cannot be assumed that measures of obligatory processing—such as the Stroop task—are direct indicators of capacity usage.

The dissociation between automaticity criteria demonstrated in the Paap and Ogden (1981) work dissolves the seeming paradox in the developmental studies employing the Stroop task. It appears that obligatory execution of word recognition processes develops quite rapidly, but that the speed and efficiency of execution, in terms of decreasing resource use, continue to develop even after recognition has become obligatory. Early theorists had described automatic processes as being fast, unconscious, obligatory, and effortless and had implied that these properties were almost totally redundant. More recent theorizing has favored the

position that: "There are no strong theoretical reasons to believe in the unity of automaticity. The idea that the various properties should co-occur has not been deduced from established theoretical principles, although a number of theorists . . . have asserted it as if it were fact" (Zbrodoff & Logan, 1986, p. 118).

Developmental work has confirmed the finding that speed, obligatory processing, and capacity usage are at least partially dissociable. For example, it is clear that children's word recognition speed continues to decrease even after Stroop indices of obligatory processing are at asymptote (Ehri & Wilce, 1979; Stanovich, Cunningham, & West, 1981). In addition, Manis and colleagues (Manis, Keating, & Morrison, 1980; Horn & Manis, 1987; see also, Lipps Birch, 1976, 1978) have extended the use of the dual-task probe technique to children (see Bjorklund & Harnishfeger, 1987, Guttentag, 1984, Halford, Maybery, & Bain, 1986, and Kee & Davies, 1988, for demonstrations in other domains). They found that this index of capacity usage does not track either the development of speed or the development of obligatory processing. Horn and Manis (1987) extended the work of Paap and Ogden (1981) by employing words as stimuli and testing first-, second-, third-, and fifth-graders. They argued that word recognition was obligatory but also capacity demanding, and they concluded that "there may be a developmental asynchrony between automaticity in the sense of obligatory processing (Stroop-type test) and automaticity in the sense of limited attentional allocation" (p. 106).

Most recent research has thus focused on individual components of the several dissociable properties once lumped together under the automaticity rubric. The issue of resource usage has been separated from issues of speed and obligatory execution. The moral of the experimental work with adults (Humphreys, 1985; Logan, 1985; Paap & Ogden, 1981; Zbrodoff & Logan, 1986) and with children (Ehri & Wilce, 1979; Horn & Manis, 1987; Manis et al., 1980; Stanovich, Cunningham, & West, 1981) is that the allocation of processing resources must be measured directly (for example, by a dual-task procedure) rather than by measures like Stroop interference. The latter cannot safely be used as a proxy measure of resource use because it is tapping a partially dissociable aspect of automaticity. Similarly, speed of execution is not synonymous with either obligatory execution, capacity usage, or conscious intent. Although we would surely expect some intercorrelations among these properties, each must be theoretically differentiated and measured with separate techniques.

MODULARITY IS KING: INFORMATION ENCAPSULATION

The recognition that Stroop indicators did not directly tap resource use rendered the developmental findings using this methodology somewhat less paradoxical, but ultimately did little to bolster limited-capacity mod-

els of reading. The reason for this was that the developmental trends involving the dual-task technique did not quite coincide with resource models of reading either (Horn & Manis, 1987). Thus, after almost 10 years of popularity, resource-based theories of reading began to engender increasing skepticism. When, in the early 1980s, an alternative concept began to garner the attention of researchers, models of reading based on cognitive resource limitations had already begun to lose their preeminence.

The focus in reading theory during the mid to latter 1980s shifted away from cognitive resource issues and toward another property associated with the automaticity concept. This property goes under a number of different names and has been discussed by several different investigators. Humphreys (1985) has described the property and some of its alternative terminology: "If word processing does proceed involuntarily on at least some occasions, there are some interesting implications concerning the control of such operations. For instance, one possibility is that control operates locally so that once a set of word-processing procedures is activated, it runs to completion and cannot be amended by other higher order processes (i.e., it is 'cognitively impenetrable'; see Pylyshyn, 1981). Such processes may be termed functionally autonomous (Forster, 1979). An implication of this is that word processing cannot be benefited by other ongoing processes (e.g., see Fodor, 1983). This is a different prediction from that which holds that the effects of word processing cannot be prevented (cf. the argument that processing is involuntary), since it is feasible that subjects are unable to prevent a particular process but they may still supplement it when required" (pp. 292–293).

The property of "functional autonomy" or "cognitive impenetrability" has garnered enormous attention since it was made the centerpiece of Fodor's (1983, 1985) controversial concept of modularity. Modularity, like automaticity, is a complex construct that conjoins a number of separate concepts. Indeed, modularity and automaticity are partially overlapping constructs. For example, modular processes are fast and obligatory, like automatized processes. However, Fodor emphasized the concept of domain specificity as a feature of modularity, an idea missing from most discussions of automaticity.

More importantly, low resource use is not a defining feature of a modular process, as it was in early theorizing about automaticity. Fodor (1985) points out that his modern version of a "vertical faculty psychology" does not share Gall's definition of lack of competition for horizontal resources: "I take the essential fact about modularity to be *informational* (not resource) encapsulation" (p. 37). Instead, it is the property of information encapsulation that is the defining feature of a modular process, according to Fodor. Information encapsulation (or

"functional autonomy", or "cognitive impenetrability") means that the operation of a module is not controlled by higher level processes or supplemented by information from knowledge structures not contained in the module itself: "The claim that input systems are informationally encapsulated is equivalent to the claim that the data that can bear on the confirmation of perceptual hypotheses includes . . . considerably less than the organism may know. That is, the confirmation function for input systems does not have access to all of the information that the organism internally represents; there are restrictions upon the allocation of internally represented information to input processes" (1983, p. 69).

Fodor (1983) views processes such as basic speech perception and face perception as candidates for modular input systems and in his book cites numerous instances of where, in these domains, "at least *some* of the background information at the subject's disposal is inaccessible to at least some of his perceptual mechanisms" (p. 66). The enormous attention garnered by Fodor's book *The Modularity of Mind* contributed to a trend already discernible in theories about individual differences in reading skill: a shift from concentration on issues of cognitive resource use to an emphasis on the issue of knowledge representation.

Although Fodor rejects the idea of acquired modularity and equivocates in applying the modularity concept to reading, many other cognitive scientists have endorsed the idea of acquired modularity as theoretically coherent (Forster, 1979; Humphreys, 1985; Logan, 1985; McLeod, McLaughlin, & Nimmo-Smith, 1985; Perfetti & McCutchen, 1987; Seidenberg, 1985; Sternberg, 1985). Others have applied the modularity concept to the process of word recognition and its development (Forster, 1979; Perfetti, in press; Perfetti & McCutchen, 1987; Seidenberg, 1985; Stanovich, 1986, in press a, b; Stanovich et al., 1985; Stanovich & West, 1983a). Interestingly, perhaps more actual empirical work has been done in the acquired domain of visual word recognition than in some of the other hypothesized modular domains that Fodor (1983) originally championed. In addition, it should also be noted that the theoretical claims in the area of visual word recognition have been more restricted to questions of the nature of information encapsulation (Seidenberg, 1985; Stanovich & West, 1983a) and have not generally included the more far-reaching and tenuous claims that Fodor makes in his conceptualization of modularity (e.g., innateness, hard-wiring, specific ontogenic sequencing).

The important idea that information encapsulation could be acquired meshed perfectly with trends in the literature on context effects in the development of word recognition skills. Work emanating from tests of verbal efficiency theory (Perfetti & Roth, 1981; Perfetti, 1985) and from the interactive-compensatory model (Stanovich, 1980) had indicated that the effects of background knowledge and contextual information attenu-

ate as the efficiency of word recognition processes increases (Perfetti et al., 1979; Perfetti & Roth, 1981; Stanovich, West, & Feeman, 1981; West & Stanovich, 1978).

Thus, one major theoretical trend in developmental reading theory is to view word recognition as becoming increasingly encapsulated (informationally) as processing efficiency develops. Indeed, this trend in the developmental literature on reading is far more empirically well established than are any conclusions about resource use or obligatory processing. Thus, even before the appearance of Fodor's monograph, reading theorists had featured the concept of information encapsulation more prominently in their theories. For example, a critical principle from Perfetti's verbal efficiency theory is that "Verbal efficiency is the quality of a verbal processing outcome relative to its cost to processing resources" (1985, p. 102). Thus, Perfetti's concept encompasses both the quality of the representation that is the output of a processing operation and the resources expended on the operation.

THE AUTONOMOUS LEXICON IN READING THEORY: INCREASING THE FOCUS ON REPRESENTATION

In subsequent elaborations of his theory, Perfetti (in press; Perfetti & McCutchen, 1987) has increased the emphasis on issues of representation quality and encapsulation and has decreased the emphasis on the issue of resource use. In its latest incarnation (Perfetti, in press; Perfetti & McCutchen, 1987), verbal efficiency theory highlights the development of a large autonomous lexicon—orthographic/phonological representations of words that are precise enough that they can be accessed without the aid of background knowledge or contextual expectations—as the key to fluent reading. This emphasis is, of course, consistent with the evidence discussed earlier indicating that it is the word recognition processes of less-skilled readers that are characterized by interactive activation from higher-level knowledge sources such as contextual expectations (Perfetti & Roth, 1981; Stanovich, 1980). However, the new conceptualization is different from earlier versions of verbal efficiency theory (Perfetti & Lesgold, 1977, 1979) in that it de-emphasizes issues of capacity use and intensifies the emphasis on the property of information encapsulation.

Perfetti (in press) argues that while encapsulated processes probably share characteristics of automatic processes such as their speed, obligatory execution, and low-resource use, these properties are not primary, but are instead secondary concomitants of encapsulation. The key causal property is the development of a high-quality representation in memory that allows autonomous access: "The entailments of acquired impenetrability . . . leave open the question of whether resources are required by the impenetrable process. It does assume that the impenetrable process

cannot be penetrated or inhibited. A young reader might well have impenetrable processes that nevertheless require resources. However, it is generally the case that the potential for resource savings is a function of the representation quality just as impenetrability is" (p. 29). Likewise, processing speed is the result of high-quality lexical representations. Speed is an outcome of the primary property—well-specified lexical representations—and thus is an imperfect indicator of encapsulation. Speed, in itself, however, is not the most important characteristic.

WHY MODULARITY?

If informational encapsulation, rather than resource allocation, has become the nexus of current theories of individual differences in reading ability, we must still address the question of how encapsulation determines increases in reading ability. In short, we may ask the question of why information encapsulation is a benefit to a processing system engaged in a task-like reading. After all, one advantage of the resource notion was the common-sense way in which that mechanism explained reading growth. Freed resources from lower-level decoding processes were allocated to higher-level comprehension processes, which then operated with greater efficiency. Is there an equally parsimonious way in which information encapsulation accounts for increased reading efficiency with increased experience and practice? There is—and here again reading theory has marched in step with developments in cognitive science.

Discussing the computer analogy to human information processing that is popular in some domains of cognitive science, Fodor (1983) argues that researchers have inappropriately deemphasized the importance of making contact with the environment and have overly focused on Turing machines that are closed computational systems: "the sole determinants of their computations are the current machine state, the tape configuration, and the program, the rest of the world being quite irrelevant to the character of their performance; whereas, of course, organisms are forever exchanging information with their environments" (p. 39). What follows, according to Fodor, is that "what perception must do is to so represent the world so as to make it available to thought" (p. 40). In short, higher-level processing operations and inference-making processes will work more efficiently when perceptual processes deliver to them accurate representations of the world. The types of perceptual processes that do this best are modular ones—input systems that fire without accessing all of the organism's background information and beliefs. Modular cognitive processes are like reflexes in that "they go off largely without regard to the beliefs and utilities of the behaving organism" (1985, p. 2).

Modular processes are thus isolated from background knowledge, be-

lief, and set. This confers two great advantages. One is the veridicality that results from the organism's ability to code—at least at some level—the features of the environment without distortion. As Fodor, in his inimitable style, points out: "The ecological good sense of this arrangement is surely self-evident. Prejudiced and wishful seeing makes for dead animals" (1985, p. 2). The second advantage—that of speed—follows along these same lines: "Automatic processes are, in a certain sense, deeply unintelligent; of the whole range of computational . . . options available to the organism, only a stereotyped subset is brought into play. But what you save by this sort of stupidity is *not having to make up your mind,* and making your mind up takes time" (1983, p. 64).

Referring to Ogden Nash's "If you're called by a panther/don't anther", Fodor argues that what the organism needs is a panther identification mechanism that is fast and that errs only on the side of false positives. Thus, "we do not want to have to access panther-identification information from the (presumably very large) central storage . . . on the assumption that large memories are searched slowly" (p. 70). In fact, even if such access were fast, it would not be efficacious because "the property of being 'about panthers' is not one that can be surefootedly relied upon. Given enough context, practically everything I know can be construed as panther related; and I do not want to have to consider everything I know in the course of perceptual panther identification. . . . The primary point is to so restrict the number of confirmation relations that need to be estimated as to make perceptual identifications fast" (p. 71), "Feedback is effective only to the extent that, *prior* to the analysis of the stimulus, the perceiver knows quite a lot about what the stimulus is going to be like. Whereas, the point of perception is surely, that it lets us find out how the world is even when the world is some way that we don't expect it to be" (p. 67).

In short, an advantage accrues to encapsulation *when the specificity and efficiency of stimulus analyzing mechanisms is great relative to the diagnosticity of the background information that might potentially be recruited to aid recognition.* This is a point that has fundamental importance for reading theory.

MODULARITY AND READING THEORY

The debate in the cognitive science literature regarding the benefits of encapsulation finds immediate correspondence with issues in the reading literature. One of Fodor's (1983, 1985) recurring themes was that "poverty of the stimulus" arguments inherited from the "New Look" period of perceptual research had led cognitive psychology astray. An analogous argument has influenced reading theory during the last decade. For example, Kintsch's (1988) construction-integration model specifically re-

jects "New Look" and early AI assumptions (e.g., Schank, 1978) of context-driven and knowledge-saturated perceptual processing. In the construction phase of his model, a network of text-based propositions is formed and linked to knowledge structures in a purely bottom-up manner. In the integration phase, activation spreads through the network and stabilizes in a connectionist manner to determine a coherent interpretation. In the construction-integration model, text information contacts and shares activation with knowledge structures, but comprehension is not "driven" by knowledge-based expectations in the traditional top-down fashion. Thus, "modal models" of reading have migrated away from expectancy and "strong" schema theories (see Kintsch, 1988) toward theories stressing autonomous processing and connectionist architectures (Rumelhart & McClelland, 1986; Schneider, 1987; Sejnowski & Rosenberg, 1986; Tanenhaus, Dell, & Carlson, 1988; Tanenhaus & Lucas, 1987).

Similarly, models of reading acquisition and individual differences in reading ability were dominated for a considerable time by "top-down" conceptualizations that borrowed heavily from the New Look in perception (e.g., Smith, 1971). These models strongly emphasized the contribution of expectancies and contextual information in the process of word recognition. Using the current terminology, top-down models posited that developmental changes in reading skill were characterized by word recognition processes that were more heavily penetrated by background knowledge and higher-level cognitive expectancies. As previously discussed, when the appropriate developmental and individual differences data were collected, they demonstrated exactly the opposite: reading skill increases as word recognition processes become increasingly encapsulated (Perfetti; 1985, in press; Perfetti & Roth, 1981; Stanovich, 1980, 1986, in press a, b).

It appears that reading theory—at least regarding word recognition—went wrong in exactly the same ways as did perceptual theory in cognitive psychology. First, "poverty of the stimulus" arguments were overgeneralized. Reading theorists were considerably influenced by analysis-by-synthesis models of speech perception and interactive models of recognition that derived from artificial intelligence work in speech perception (Rumelhart, 1977). The problem here is that the analogy to written language is not apt. The ambiguity in decontextualized speech is well known. For example, excised words from normal conversation are often not recognized out of context. This does not hold for written language, obviously. A fluent reader can identify written words with near perfect accuracy out of context. In short, the physical stimulus alone completely specifies the lexical representation in writing, whereas this is not always true in speech. The greater diagnosticity of the external stimulus in read-

ing, as opposed to listening, puts a greater premium on an input system that can deliver a full representation of the stimulus to higher-level cognitive systems.

Another problem concerns the assumptions that have been made about the properties of contextual information. Laboratory demonstrations of contextual priming effects have often led to an overestimation of the magnitude of facilitation to be expected from contextual information, because these studies—often for sound theoretical reasons—employed stimulus materials that had strong semantic associations and that were vastly more predictable on a word-by-word basis than is natural text (Gough, 1983; Stanovich & West, 1983b). Also, the writings of top-down theorists—ignoring evidence on text redundancy—often give the impression that predicting upcoming words in sentences is a relatively easy and highly accurate activity. Actually, many different empirical studies have indicated that naturalistic text is not all that predictable. Alford (1980) found that for a set of SAT-type passages, subjects needed an average of more than four guesses to correctly anticipate upcoming words in the passage (the method of scoring actually makes this a considerable underestimate). Across a variety of subject populations and texts, a reader's probability of predicting the next word in a passage is usually between .20 and .35 (Aborn, Rubenstein, & Sterling, 1959; Miller & Coleman, 1967; Perfetti et al., 1979; Rubenstein & Aborn, 1958; Gough, 1983). Indeed, as Gough (1983) has shown, this figure is highest for function words, and is often quite low for the very words in the passage that carry the most information content.

Thus, we have in reading precisely the situation where an enormous advantage accrues to encapsulation: the potential specificity of stimulus analyzing mechanisms is great relative to the diagnosticity of the background information that might be recruited to aid recognition. In short, a consideration of the stimulus ecology of the reading task has converged with the actual empirical data on the development of word recognition skill and has led an increasing number of investigators to endorse the idea of the acquired modularity of the word recognition module.

Current reading theory is thus quite interestingly bifurcated. The idea that background knowledge should saturate central processes of text inferencing, comprehension monitoring, and global interpretation is now widely accepted (Anderson, 1984; Anderson & Pearson, 1984; Fincher-Kiefer, Post, Greene, & Voss, 1988; Paris, 1987; Paris, Lipson, & Wixson, 1983; Spiro, Bruce, & Brewer, 1980; Wixson & Peters, 1987), while at the same time the advantage of modularly organized input processes is acknowledged. Indeed, the dangers of cognitive penetrability at too low a level have become apparent in discussions of nonaccommodating reading styles (Kimmel & MacGinitie, 1984; Maria & MacGinitie, 1982; Stanov-

ich, Cunningham, & Russell, in press). As Evans and Carr (1985) point out: "If print-specific encoding mechanisms send incomplete or erroneous data to the language comprehension processes, what could result but an incomplete or erroneous understanding of the text? In addition, the more powerful the language skills that are applied to the erroneous data, the greater the chance that a seemingly acceptable interpretation can be constructed" (p. 342). Of course, there is an analogy here to Fodor's "panther detector." The organism is much better off with a correct rendition of the stimulus as opposed to a sloppy stimulus representation and a geometric explosion of "panther-related" general information. Similarly, the reader is better off having the proper lexical entry activated.

THE FUTURE OF THE RESOURCE CONCEPT IN READING THEORY

This rather extended discussion of the place of the modularity concept in modern reading theory was necessary in order to fully explain the context in which reading researchers have gradually drifted away from the resource concept toward questions of representation quality and encapsulation. This shift has also characterized generic resource theory even outside of the reading area. For example, Logan's (1988) recent instance theory of automatization "reflects a shift from reliance on a general algorithm to reliance on memory for past solutions. Thus automatization reflects the development of a domain-specific knowledge base; nonautomatic performance is limited by a lack of knowledge rather than by scarcity of resources" (p. 501). Instance theory "accounts for many of the facts addressed by the modal view without assuming any resource limitations, attentional or otherwise" (p. 519).

It should not be inferred, however, that the resource concept is without supporters among reading theorists. Many researchers do believe that the capacity notion is still viable. It is just that the issues of the quality of lexical representations and of information encapsulation seem to many investigators to present more tractable theoretical problems, given our currently available empirical techniques.

There are several other reasons why the future of the concept of cognitive resources in reading theory will probably be characterized by only sporadic enthusiasm among reading researchers. First, the checkered history of the dual-task technique in experimental psychology has contributed greatly to the skepticism of investigators in allied fields. The literature on the methodological pitfalls and artifacts involved in using the technique seems to grow faster than the literature demonstrating that the technique can solve theoretical problems having to do with cognitive resources (Allport, 1980; Fisk, Derrick, & Schneider, 1986–87; Howe & Rabinowitz, 1989; Jonides, Naveh-Benjamin, & Palmer, 1985; Lane,

1977; Logan, 1985; Logan, Zbrodoff, & Fostey, 1983; McLeod, 1978; Navon & Gopher, 1980; Salthouse, 1988).

In addition, the whole concept of generic cognitive resources, as it is commonly used in cognitive psychology, continues to come under conceptual attack (Allport, 1980, 1987; Brainerd & Kingma, 1985, Brainerd & Reyna, 1988, 1989; Hirst & Kalmar, 1987; Logan, 1985; Navon, 1984, 1985, in press; Neumann, 1987). Navon's (1984) well-known critique severely questioned the falsifiability of the resource notion and concluded "The claim that provisions for processing may be likened to resources drawn out of a limited reservoir does not seem to be entailed by the results of any known test: Alternative models that do not assume any limit on resources were seen to accommodate empirical findings predicted from this claim" (p. 231). Allport (1980) has leveled similar criticisms of unfalsifiability.

Thus, reading researchers seem to have become uncomfortable with using a task and a concept that seem to be so tenuous in the originating cognitive psychology literature. Reactions to research employing the technique in the reading domain have been decidedly lukewarm. For example, Britton and associates (Britton, 1980; Britton, Holdredge, Curry, & Westbrook, 1979; Britton & Tesser, 1982; Britton, Westbrook, & Holdredge, 1978) have imaginatively applied the dual-task technique in the domain of ongoing reading comprehension. However, some of the findings have been paradoxical, such as easier texts using more capacity (Britton et al., 1978), and the number of alternative explanations for any particular finding appears to be inordinately high (Britton, Glynn, Meyer, & Penland, 1982; Britton & Tesser, 1982; Larochelle, McClelland, & Rodriguez, 1980). Nevertheless, one would have suspected just a few years ago that the intriguing findings of the Britton group would have spawned more experimentation with this technique. Instead, there has been surprisingly little work by other investigators. One can only surmise that confidence in the task is at a low ebb and that interest in the whole resource concept is on the wane in reading theory.

Other attempts to empirically elaborate the generic resource concept within reading models have resulted in theoretical developments that undermined the concept. For example, the reading span task developed by Daneman and Carpenter (1980) initially seemed an excellent indicator of individual differences in central executive capacity. In this task, the subject reads aloud (or listens to) a series of increasingly longer sets of sentences and attempts to remember the last word in each sentence. However, the complexity and lack of process specificity of the task were criticized by Baddeley, Logie, Nimmo-Smith, and Brereton (1985): "Both a strength and a weakness of the working memory span measure is its complexity. It involves a number of subcomponents, including compre-

hension, the selection and operation of strategies, learning, and recall. Its richness and complexity mean that it has a very good chance of capturing those aspects of working memory that are important, but at the same time it makes its interpretation very difficult" (p. 120).

Actually, Daneman and Tardif (1987) were quite aware of this criticism and themselves argued "A legitimate concern about the reading span test is that it is too much like reading comprehension itself . . . the complexity of the reading span processes makes interpretation of the correlation difficult" (p. 493). Thus, they conducted more thorough individual difference analyses and demonstrated that the "central executive capacity" presumed to underlie the original measure fractionated along domain specific lines. These investigators recently concluded that: "The findings of the larger study showed a high degree of domain specificity. . . . Reading is limited by a system specialized for representing and processing verbal or symbolic information only. . . . The picture suggests the need for abandoning the notion of a general and central limitation on information processing, a central executive" (Daneman & Tardif, 1987, pp. 501–502).

One additional reason for the relative unpopularity of the cognitive resource concept in current research on individual differences in reading is that the concept seems to have a ready affinity with g models of individual differences (Rabbitt, 1988; Salthouse, 1988). As Rabbitt (1988) notes: "Many cognitive psychologists find the g model uninteresting. Most cognitive models treat the cognitive system as a highly differentiated structure in which component modules have considerable autonomy, but the g model is not concerned with whether or what modular subsystems exist and merely predicts that if they do, they must all be affected by the presence or absence of a ubiquitous 'brain grease' " (p. 172). Similarly, global trait models of individual differences in reading ability are currently exceedingly unpopular (Carr, Brown, & Vavrus, 1985; Carr & Levy, in press; Cunningham, Stanovich, & Wilson, in press; Frederiksen, 1980; Lipson & Wixson, 1986; Singer, 1982; Stanovich, Cunningham, & Feeman, 1984). To the extent that the resource concept remains intertwined with the g construct, it will engender little enthusiasm among reading researchers concerned with individual differences.

However, it is always important to distinguish the theoretical usefulness of a concept as an explanation for individual differences in a skill from its centrality as an underlying general determinant of performance for all subjects. It is perfectly possible for a mechanism to enable a particular function, but not to be a generator of individual differences in the function (see Daneman & Tardif, 1987, pp. 506–507). This point continually needs reiterating in reading theory, because it is quite common for theorists to argue that a particular process, strategy, or mechanism is ubiquitous in reading and then go on to argue for the process as an un-

derlying cause of individual differences. It is rarely considered that the very ubiquity of the process may be precisely the thing that prevents it from being a potent source of individual differences (Stanovich, 1986, pp. 368–369). An analogous error commonly occurs in many areas of developmental and educational psychology where determinants of variability in a trait are often confused with the determinants of its absolute level or general developmental course (McCall, 1981; Rutter, 1983; Stanovich, 1986, p. 392). Thus, it may well be true that it is primarily in the area of individual difference theorizing where the resource concept seems to be losing ground. As a concept in a "modal model" of the generic reading process it may be more viable.

DIVORCING THE NOTION OF COGNITIVE RESOURCES FROM "CONSCIOUSNESS"

We have previously outlined how, in the area of reading theory, the undisciplined use of terms has contributed to ensnarling the cognitive resources concept in considerable confusion and has created seeming empirical paradoxes. For example, it was illustrated how the conflation of the idea of capacity-free processing with the notion of obligatory processing in the elaboration of the automaticity concept led to such a seeming paradox. There is, unfortunately, even further potential for conceptual confusion than has been outlined, and perhaps a few warnings are in order.

In describing the experience of automatic processing during reading, LaBerge and Samuels, in their original article, tell us: "Apparently we have not given a bit of attention to any of the decoding processes that have been transforming marks on the page into the deeper systems of comprehension" (1974, p. 314). Similarly, Posner and Snyder (1975) reiterate the theme: "The mechanisms of conscious attention are limited in capacity" (p. 670). Both sets of investigators conflate automatic, resource-free processing with the lack of conscious attention and both simultaneously link capacity-demanding processing with conscious attention. Both of these seminal papers thus sustained a strong tendency to link resource use with conscious awareness. Again, this is probably a theoretical mistake. It is very conceivable that even processes that do not draw our conscious attention might utilize cognitive resources (Humphreys, 1985).

Indeed, the stronger point could be advanced that, as in many areas of psychology, the indiscriminate, and undiscriminating, use of folk terms such as "conscious" and "awareness" has contributed to the conceptual confusion in theorizing about resource issues and that the theoretical landscape would be clearer if the terms were barred altogether. This is not a new recommendation, although previous cautions have largely gone

unheeded. It is well-established that our use of the term "conscious" is considerably confused (Armstrong & Malcolm, 1984; Dennett, 1969; Lyons, 1986; Rorty, 1979; Ryle, 1949; Smith & Jones, 1986; Wilkes, 1984); and this is surely not surprising since, as Hooker (1975) argues, "Language will surely be seen as a surface abstraction of much richer, more generalized processes in the cortex, a convenient condensation fed to the tongue and hand for social purposes" (p. 217).

In addition, connectionist models, modular brain theories involving semiautonomous processors, dissociation phenomena increasingly uncovered in neuropsychology and experimental psychology (Allport, 1980; Boden, 1988; P. M. Churchland, 1988; Dennett, 1978; Hofstadter, 1985; Kihlstrom, 1987; Minsky, 1987; Navon, in press; Nisbett & Ross, 1980; Nisbett & Wilson, 1977; Rollman & Nachmias, 1972; Springer & Deutsch, 1985; Tranel & Damasio, 1985)—all are putting tremendous stress on the integrity of our concept of "consciousness" (P. S. Churchland, 1983, 1986; Dennett, 1987, 1988; Rorty, 1979; Stich, 1983). It would seem best for resource theory to avoid linkage with such an unstable term.

Allport (1980) previously warned us that, 90 years after William James' analysis of attention "the word is still used, by otherwise hard-nosed information-processing psychologists, as a code name for consciousness. Questions regarding the limitations of concurrent human *performance* easily get confused with another, hidden agenda concerning the limitations of *consciousness*. Worse, 'attention' (or 'consciousness'?) is sometimes discussed as though it were yet another—but always unspecified!—information process" (p. 113). Allport (1980) provides examples from a literature that Claxton (1980, p. 17) claims is "peppered with bits of double-speak." Quoting a common and widely used definition of controlled processes from Shiffrin and Schneider (controlled processes are "activated under control of, and through attention by, the subject," 1977, p. 156), Allport asks "What can these terms mean? Is 'the subject' equivalent to the whole system, long-term memory and all? . . . Or does 'the subject' refer to some sub-part of the system, a ghost-in-the-machine? . . . And how does 'attention' affect the nature of the processes, associative or otherwise, that can occur? . . . The mechanism of 'control processes' and presumably therefore of 'attention' (which control processes supposedly require) is quite simply 'the subject'! I sometimes wonder whether all those psychological theories that propose, as their central mechanism, a general-purpose limited-capacity central processor are not similarly homunculus theories, though sometimes better disguised" (pp. 122–124).

Philosophers have pressed this point even more forcefully. P. M. Churchland (1988) asks: "How could one possibly be blind and not know it? See with no visual field? Write freely but not read a word? Or sincerely

deny ownership of arms and legs attached to oneself?" (Churchland, 1988, p. 144). Yet these are all demonstrated phenomena in neuropsychology. P. S. Churchland (1986) argues:

> It is possible that the folk theory that gives "awareness" its meaning might turn out to be displaced by a superior theory. Accordingly, just as it turned out that there was no such thing as impetus, there may be no such thing as awareness. This is not as bizarre as it first sounds. Presumably there is *some* monitoring mechanism or other chugging away in the mind-brain in virtue of which our current employment of the concept "awareness" can get a foothold—just as there is something or other going on in the world in virtue of which the employment of the concept "impetus" got a foothold. But we may misapprehend it, folk psychology may be a thoroughly muddled theory of mental business, and a newer and better theory may yield a more satisfactory characterization of it (p. 309).

Although many cognitive psychologists still seem reluctant to heed Allport's (1980) advice, there are increasing signs that investigators are recognizing both that something is amiss with our terminology and that, fortunately, theoretical developments in the cognitive sciences do promise better conceptualizations. Kahneman and Treisman (1984) make this point in a discussion of the automaticity concept: "The evidence of dissociation phenomena suggest that it may at times be as difficult to assign epistemic states to individuals as it is to assign such states to organizations. It now appears at least conceivable that future discussions of attention will be conducted within the framework of an organizational metaphor for the mind. . . . It is disconcerting, but perhaps also encouraging, that many of the questions with which we have been concerned for years—including the question of automaticity that is the focus of this chapter—will turn out, in such a framework, to be slightly out of focus. Some 'attentional' limits may turn out to be failures in the dissemination of information rather than its processing" (Kahneman & Treisman, 1984, p. 56). Navon (in press) has argued just this in his theory that explains "attentional" phenomena as decouplings and propagations in a distributed modular system.

It is hoped that there will be a continued retreat from conceptualizations that conflate resource use with "conscious attention." The concept of cognitive resources is currently in enough trouble, without taking on the added burden of our tenuous understanding of "consciousness." If there is a way out of the present thicket in which the concept of cognitive resources finds itself, it will be through a more thoroughly operational conceptualization, rather than through an even fuzzier folk psychology.

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