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Bartlett's Schema Theory and Modern Accounts of Learning and Remembering

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Although Bartlett's (1932) schema theory has been highly influential in modern cognitive psychology, it has often been misunderstood. This paper (a) discusses Bartlett's schema theory along with modern schema theories, (b) argues that the problems in the interpretation of Bartlett's writing arise because his theory is fundamentally different from modern schema theories, (c) shows that Bartlett's theory, but not modern schema theories, can be explained in terms of the brain's constructive and self-regulatory processes, and (d) discusses such a brain-based theory of learning and remembering in the context of recent developments in biofunctional cognition.

Contact between Bartlett's (1932) and modern constructivist theories can be traced at least as far back as Neisser's (1967) seminal book that laid the foundation for modern information processing psychology. But it was not until the publication of several now classic papers in the mid-seventies (Markus, 1977; Minsky, 1975; Rumelhart, 1975; Rumelhart and Ortony, 1977; Schank and Abelson, 1975; Spiro, 1977) that widespread interest in Bartlett's schema theory emerged. This landmark development occurred only a few years after Zangwill (1972) declared that the constructive theory, "in my view never very plausible, is best forgotten" (p. 127). The primary factor responsible for the new development was interest in the influence of prior knowledge in perception, comprehension, and remembering. Not only did Bartlett's research represent an original and dramatic demonstration of the role of background knowledge, but it also introduced the hypothesis that this influence was medi-

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ated by the intriguing concepts of schema, construction, and reconstruction. As a result, although several other authors also received credit for their pioneering contribution to the schema-theoretic approach (e.g., Kant, 1781/1963; Piaget, 1926), there was unanimous agreement among current schema theorists, including Neisser, that modern uses of the concepts of schema and construction were most similar to Bartlett's (Thorndyke and Yekovich, 1980).

This paper argues that Bartlett's (1932) theory represents a functional approach akin to that of James (1890), Dewey (1896), Angell (1907), and Head (1920). By contrast, as noted by Neisser (1976) and others (diSibio, 1982), most modern schema theories are similar to pre-Bartlett structuralism (Titchener, 1898) and associationism (see Myers, 1931). We review the origins and global characteristics of both Bartlett's schema theory and modern schema theories and show that many of the assumptions underlying modern schema theories had already been rejected in Bartlett's comparison of his theory with associationism. Modern interpretations of Bartlett's theory are also examined. The final section discusses a biofunctional theory of learning and remembering based on the assumptions that (a) multiple independent sources and not just executive control regulate learning processes, (b) multiple independent sources and not just external input contribute to learning, and (c) there is no essential difference between comprehension, learning, and remembering.

Current Status of the Schema-Theoretic Approach

The notion of schema has played a critical role in the cognitive revolution in psychology. With the use of this concept, problems as complex as discourse comprehension (Bower, Black, and Turner, 1979; Graesser, 1981; Kintsch and van Dijk, 1978; Mandler and Johnson, 1977; Ortony, 1978; Rumelhart and Ortony, 1977; Schallert, 1976; Thorndyke, 1977), inference (Bransford, Barclay, and Franks, 1972; Spiro, 1980a), figurative uses of language (Ortony, 1979), and even the elusive concept of self (Markus, 1977; Markus and Kunda, 1986) have been brought under rigorous empirical examination. Schema theory has been identified by the National Institute of Education as the most viable approach to comprehension (Tierney, Anders, and Mitchell, 1987) and is currently used in diverse areas of psychology (see Alba and Hasher, 1983; Hastie, 1981; Markus and Zajonc, 1985; Segal, 1988). However, attempts at a precise formulation of the notion of schema have not been very successful and, as a result, the schema-theoretic approach is at a critical stage in its development.

There is widespread agreement that modern schema theory is imprecise (Alba and Hasher, 1983; Thorndyke and Yekovich, 1980), that it lacks conceptual clarity, internal consistency, and testability, and that it does not square well with data (Taylor and Crocker, 1981). Because schemas are viewed as abstract structures, current schema theory has difficulty accounting for the richness of authentic learning and remembering (Alba and Hasher, 1983; Anderson, 1984). Reactions to Bartlett's theory have also been mixed. On the one hand, Bartlett's book, *Remembering* (1932), is an increasingly popular source among researchers, and several authors have suggested that Bartlett's theory is superior to other schema theories in that it can handle such basic problems as learning (Bransford, McCarrell, Franks, and Nitsch, 1977) and affect (Spiro, 1980b; Zajonc, 1980) more readily than modern schema theories. On the other hand, modern schema theorists have found it difficult to deal with Bartlett's theory. Some have claimed that it is limited in scope, applying only to those rare circumstances that manifest gross inaccuracy in recall (see Alba and Hasher, 1983), while others have concluded that it is flawed in that it cannot account for the recall of specific or episodic knowledge (Brewer and Nakamura, 1984).

Can the problems with the notion of schema be resolved? This question, along with general dissatisfaction with modern schema theories, motivated the first author in mid 1970s to critically explore the theoretical nature of the schema. Iran-Nejad (1980) reported the early results of this exploration by suggesting that schemas must be viewed as transient structures created directly by the ongoing functioning of the nervous system, rather than static, long-term memory structures. According to Iran-Nejad (1980, 1986, 1987), much of the confusion covering the concept of schema can be clarified with the understanding that Bartlett's (1932) schema theory is fundamentally different from modern information-processing schema theories in that Bartlett viewed the schema as a transient functional pattern. Bartlett's idea that the schema is an ongoing organization constructed and upheld perhaps directly by the ongoing activity of the brain has become increasingly more attractive as some contemporary researchers find the long-term storage metaphor to be unacceptable (Bransford et al., 1977; Jenkins, 1974). The transient schema hypothesis also raises a question in light of the amount of research effort modern cognitive psychology expends on problems related to the organization of schemas in the long-term memory store. If there are no long-term memory schemas then exploring their organization is like searching for the ghost in the machine.

Some inconsistencies in the schema-theoretic literature become easier to reconcile with the understanding that even though all schema theories share concern about the influence and organization of prior knowledge, not every theory views the concept of schema in the same way. For instance, although researchers sympathetic to Bartlett's approach (e.g., Bransford et al., 1977; Spiro, 1977) experienced great difficulty, as did Bartlett, to find words to describe precisely what was meant by the term *schema*, modern theories seem to have no trouble introducing new terms for what they claim to be similar

concepts. How could this be? Bartlett (1932) was gravely concerned about the fact that the concept of schema implied "a vaguely outlined theory," "a persistent but fragmentary form of arrangement," and "a passive framework or patchwork" (see pp. 201–204); but these are precisely the type of expressions leaders in modern schema theory used to characterize schemas and their construction (see Neisser, 1967, pp. 295–296; Rumelhart, 1980, pp. 37–38). The transient schema hypothesis implies that these problems arose because Bartlett and modern schema theories speak vastly different languages and that a useful distinction can be made between *structural* schema theories, that define schemas as static, long-term memory templates, and *functional* schema theories, that view schemas as dynamic, ongoing, and continuously-evolving patterns (Iran-Nejad, 1980, 1986, 1987, 1989).

Structural Schema Theories

According to Rumelhart (1980), for all authors who use "the notion of a schema and the related notions of beta structures, frames, scripts, plans, and so on, . . . schemata truly are *the building blocks of cognition* . . . the fundamental elements upon which all information processing depends" (p. 33). Two aspects of this definition must be noted here. It states that (a) schemas are elemental building blocks or monoliths, and (b) all information processing depends on the prior availability of such building blocks in long-term memory. This suggests that no learning can occur without an incoming string of input information and a relevant pre-existing schema.

As noted by Rumelhart (1980), all versions of the structural schema theory share the same basic assumptions. For instance, they all view schema construction as the instantiation, with or without modification, of generic long-term memory structures in particular contexts: "abstract schemata program individuals to generate concrete scenarios" (Anderson, 1977, p. 423). It is possible, however, to distinguish at least three substantially different versions of the structural schema theory and discuss prototypical examples of each. These are theories that define schemas as (a) program-like frames (Minsky, 1975; Neisser, 1967), (b) nodes in an associative network (Bower, 1981; Collins and Loftus, 1975), and (c) underlying event sequences (Brewer and Lichtenstein, 1981; Graesser, Gordon, and Sawyer, 1979; Rumelhart, 1975; Schank and Abelson, 1977). The three versions differ not only in their basic assumptions but also in their historical origin.

Schema as a Program-Like Frame

Frame or template schema theories have their origin in the computer metaphor. Neisser (1967) used the computer program analogy to clarify the concept of schema. He defined a program as a "recipe for selecting, storing, recovering, combining, outputting, and generally manipulating" information (p. 8), and argued that viewing schemas as analogous to a computer program provides the much needed philosophical assurance that cognitive structures can really exist. Referring to Bartlett's (1932) work as an example, Neisser (1967) noted that "there were cognitive theorists long before the advent of the computer, . . . but, in the eyes of many psychologists, a theory which dealt with cognitive transformations, memory schemata, and the like was not *about* anything" (p. 8). A program, he added, controls the operation of a tangible machine and a psychologist who talks about program-like mental structures is doing nothing self-contradictory in the same way that "a man who seeks to discover the program of a computer is surely not doing anything self-contradictory" (p. 8). Neisser's program analogy provided a sense of concreteness to the assumption that knowledge (or mental software) is autonomous; it is analyzable directly and formalizable without the simultaneous consideration of the functional properties of the biological system. Mental schemas could literally exist in the head just as computer programs can exist on computer disk. The psychologist would not be concerned with the form in which mental schemas were stored, just as the computer software scientist would "not care much whether his particular computer stores information in magnetic cores or in thin films" (Neisser, 1967, p. 6). Rather, according to Neisser, what the psychologist would want to understand is the internal structure of individual schemas and their overall organization in the long-term memory store in the same sense that the computer software scientist would have to specify the internal structure of individual programs and the overall organization of the filing system in which those programs were kept.

The program analogy does a good job of taking much of the mystery out of the process of schema storage, retrieval, and instantiation, but it also introduces some rigid constraints. Thus, if a schema is available in long-term memory, it is retrieved and instantiated when needed in much the same way that a computer program is retrieved and runs on raw data. If no suitable long-term schema is available, perception and comprehension cannot occur. The learner simply ignores the information for which there is no available schema (Neisser, 1976).

Few psychologists today take the program analogy literally and many find the computer metaphor unacceptable as a model of human cognition (e.g., Rumelhart, 1984). Furthermore, it is noteworthy that Neisser (1976) himself was one of the first who expressed dissatisfaction with it. Nevertheless, the associated concepts continue to be used in many areas of psychology (see Andre and Phye, 1986; Lang, 1984; Pressley and McCormick, 1995).

Bartlett's schema theory, unlike Neisser's, was concerned with the functional characteristics of the system that creates knowledge and not with the

retrieval and instantiation of mental programs. For instance, Bartlett (1932) argued emphatically against the long-term storage hypothesis. Whereas Neisser (1967) stated that "no one would dispute that human beings store a great deal of information about their past experiences" (p. 5), Bartlett (1932, p. 200) did just that when he objected to Head's phrase that the cortex is "a storehouse of past impressions" (Head, 1920, p. 607). Certainly, Bartlett never used any long-term storage metaphors in relation to his own theory.

Schema as a Node in an Associative Network

Many schema theorists assume that the schema is a node in an associative long-term memory network. The network metaphor carries two types of assumptions that have to do with representation and processing. Representational assumptions deal with the static organization of knowledge in long-term memory. The principle assumption is that schemas are organized in a hierarchical network according to the associative principles of subordination, superordination, and similarity with the most complex and abstract schemas at the top and the simplest sensory schemas at the bottom. Processing assumptions deal with the construction, storage, and retrieval of knowledge. The most influential of these assumptions relates to the notion of spreading activation, proposed initially by Collins and Loftus (1975), but also used in the models proposed by Anderson (1976), Hinton (1981), and McClelland and Rumelhart (1981, 1985; Rumelhart and McClelland, 1982).

The network metaphor has been highly controversial, more so than the computer metaphor. One of its first critics was Jenkins (1974) who noted that "many of us confuse the dicta of associationism with the ground of empirical science itself . . . associationism is only one view; it is not a necessary one" (p. 786). Similarly, Bransford, Nitsch, and Franks (1977) stated that network models might explain how information that is already stored is used, but cannot "provide insights into processes by which people learn what to do to go beyond what they know" (pp. 34–35). Finally, Norman (1980) argued that "associations among memory concepts . . . [imply] much too much knowledge of the wire (or of its biological equivalent) that is to snake its way among the already existing stuff" (p. 178).

Not only did Bartlett (1932) refuse to define schemas in associative terms, but he devoted a good portion of his book contrasting his theory with associationism. Interestingly, many of the issues he raised are equally applicable today. For instance, he noted that the notion of association tells "something about the characteristics of associated details, when they are associated, but it explains nothing whatever of the activity of the conditions by which they are brought together" (1932, p. 308). Like Jenkins, Bransford, and others, Bartlett also argued that a schema is qualitatively different from "a group of [associated] elements each of which retains its specific character" (p. 197).

Why is it, then, one might ask, as did Bartlett (1932), that "although everybody now admits the force of the criticisms of associationism, the associationist principles still hold their ground and are constantly employed?" (p. 307). Perhaps this "is because the force of the rejection of associationism depends mainly upon the adoption of a functional point of view" (pp. 307–308). Bartlett prophetically stated that "in various senses, therefore, associationism is likely to remain, though its outlook is foreign to the demands of modern psychological science" (p. 308). Thus, in its most elaborate form yet, associative network modeling (Hinton and Anderson, 1981) is currently being used in the form of the rapidly expanding parallel distributed processing (PDP) approach, as a brain-inspired alternative to traditional computer-inspired models (Rumelhart, 1984; Schneider and Graham, 1992). Whether the connectionism of the PDP revolution is an alternative qualitatively different from conventional associationism and free from its long-lasting problems is a matter for the future to resolve (see Iran-Nejad and Homaifar, 2000, this issue).

Schema as an Underlying Event Sequence

Many researchers, especially those dealing with prose comprehension, define schema as a deep or underlying sequence of events or actions, and schema instantiation as the process of matching the underlying sequence and the input sequence. Event schemas have been postulated by story grammarians (Mandler and Johnson, 1977; Rumelhart, 1975; Stein and Glenn, 1979), who distinguish between surface and underlying narrative events (Brewer and Lichtenstein, 1981; Rumelhart, 1975) in the same fashion that linguists distinguish between surface and underlying structures for sentences (Chomsky, 1965). Action schemas have been postulated by script theorists (Schank and Abelson, 1977) who have investigated memory for stereotypic or overlearned activities (i.e., shopping at a supermarket) that lead to a certain goal or consequence. These two types of schema theories are briefly described below.

The story grammar approach. The first general story grammar approach that adopted the formalism developed by sentence grammarians was proposed by Rumelhart (1975). Rumelhart's explicit concern was with the sequential well-formedness of stories: "just as simple sentences can be said to have an internal structure, so too can stories be said to have an internal structure . . . the notion of 'well-formedness' is nearly as reasonable for stories as it is for sentences" (p. 211). Rumelhart suggested that the difference between a random sequence of events and a well-formed story is that, unlike the random

sequence, the sequence of events in the well-formed story can be related, via rule-governed constructive processes, to a generic underlying sequence of events. He, therefore, assumed that there exist generic underlying structures in long-term memory that guide the comprehension of particular stories.

Mainly because of an important review by Black and Wilensky (1979), researchers have realized that, as a general theory, story grammar is no longer a fruitful area of research. Using the same string of sentences that Rumelhart (1975) used to launch his story grammar, Black and Wilensky demonstrated that underlying constituent structures cannot guide story comprehension because, "in order to determine the constituent structure of the story, we need to first have understood the story" (p. 227). Although, as Wilensky (1983) put it, "the mistake in the analogy to sentence grammars should by now be obvious," (p. 582) the story grammar approach is far from extinct (see Yussen, Huang, Mathews, and Evans, 1988). A few years after Black and Wilensky's devastating review, Brewer and Lichtenstein (1981, 1982) restated the analogy again arguing that "it is necessary to make a theoretical distinction between the two [underlying and surface] levels in narrative" and that this distinction "provides advantages in theorizing about narratives that are analogous to the advantages that the distinction between abstract structure and surface structure provides for sentences" (p. 365). For Rumelhart (1975), as well as for Brewer and Lichtenstein (1981, 1982), the underlying structure is a long-term memory schema in which the events in a particular story "are organized in terms of their temporal sequence in some presumed event world" (p. 365).[1]

The script approach. As used by schema theorists, a script "is a schema that underlies a frequently enacted activity, for example, going to a restaurant, or a less frequent, but conventional activity, for example, getting married" (Graesser, Gordon, and Sawyer, 1979, pp. 319–320). For instance, every time a person goes to a restaurant, or brings the concept to mind, he or she retrieves and uses his or her restaurant schema, which consists of such generic events as being seated, ordering, being served by a waitress or waiter, eating, paying, and leaving.

[1] In all fairness to Brewer and Lichtenstein (1981), the goal of their research was not to restore the definition of story grammar. They were interested in a solution to another very fundamental problem in the realm of story grammar. It had already been argued that the focus on the analysis of the characteristics (e.g., abstract structures and rules) of the story software (or mental software, in general) can put great distance between investigators and those characteristics that serve to make the stories what they are (Iran-Nejad, 1980). The fact that the mainstream story grammar research at the time had never investigated surprise and other similar story characteristics was viewed as tacit evidence in support of the claim. The phenomenal experience of surprise, illustrated by means of a surprise-ending story (Thurmond, 1978), was assumed to have more to do with the functional characteristics of the brain than with the rules governing the structural arrangement of such mental products as events, propositions, or sentences in the story. The reasoning was that the functional characteristics of the system and the structural characteristics of its products belong to two very different worlds requiring an inter-level, as opposed to an intra-level approach to their study (Iran-Nejad, Clore, and Vondruska, 1984). Thus, to use again the analogy that Iran-Nejad (1980) used to illustrate the same point, we might say that "analyzing the [structural] features of the pictures a camera takes may never tell us anything about what the camera itself is like" adding that "text and story grammarians need to seriously consider these problems" (Iran-Nejad, 1980, p. 30). In a well-designed set of studies, Brewer and Lichtenstein (1981, 1982) managed to challenge this claim by demonstrating that indeed the structural arrangement of the events in the story could be used to manipulate surprise, curiosity, and suspense. Their evidence, therefore, challenges the claim illustrated with the camera metaphor and the surprise-ending story (see Iran-Nejad, 1983). It also endows the story grammar approach with what it has always been missing, namely, a firm handle on the entertainment function of stories. Nevertheless, structural arrangement may not be the best context for Brewer and Lichtenstein's important results.

The script is probably the most well-specified of the concepts related to schema. Specifically, a great deal of research in schema theory has focused on the influence of schemas on the encoding or retrieval of schema-consistent information (see Alba and Hasher, 1983; Thorndyke and Yekovich, 1980). However, as already suggested, structural schema researchers have seldom considered constructive processes other than those involved in schema instantiation and, consequently, they have assumed that information unrelated to, or inconsistent with, the schema being instantiated is ignored at the time of encoding. Script theorists, on the other hand, have articulated some of the conditions for the encoding and retrieval of schema-unrelated or schema-inconsistent events (Bower, Black, and Turner, 1979; Schank and Abelson, 1977).

A widely-examined hypothesis in this regard is the notion of script-pointer-plus-tag (SP+T) [Graesser, 1981; Graesser et al., 1979]. According to this hypothesis, when a passage is comprehended, an abstract memory representation for it is constructed that consists of a pointer and a set of tags. The "pointer" points to the generic script that guides the comprehension of the original passage, while "tags" attach to any script-unrelated or script-inconsistent items that the reader encounters during reading. At retrieval, individuals use the pointer to copy the events stored in the generic long-term memory script into the short-term memory buffer in an all-or-none fashion, that is, regardless of whether these events were explicitly presented in the original passage. And they use the tags to copy otherwise isolated items of unrelated or inconsistent information. Thus, the SP+T enables the individual to reconstruct an episodic scenario of the original input that contains (a) the schema-consistent generic information and (b) other schema-inconsistent or schema-unrelated events.

Like other schema theories, the script notion can explain the findings that generic schema-consistent information is often remembered better than schema-irrelevant information and that recall often results in inferential intrusions (Anderson and Pichert, 1978; Pichert and Anderson, 1977; Spiro, 1977, 1980a; Thorndyke, 1977). Having heard a passage about eating in a

restaurant, an individual is more likely to remember that the passage stated that the customer ordered a drink, as compared to remembering that the passage contained a statement about the waiter using a pencil to take down the order. The individual is also likely to recall falsely that the passage stated that the customer paid the bill before leaving, due to the all-or-none copying of the contents of the generic schema. However, unlike other versions of schema theory, the SP+T hypothesis can also explain why the individual would be likely to remember if the passage contained an atypical statement (e.g., a dog accompanied the waiter to every table).

But comprehension and recall of scripted activities seem to require more than a generic underlying sequence. One must, for instance, explain the recall of nongeneric script-consistent actions. In fact, the SP+T hypothesis seems to create problems of its own. Note that the pointer-plus-tags notion suggests that for every to-be-remembered situation, people store a pointer to a generic schema and a tag with every unrelated or inconsistent event. This implies that any event that is nongeneric and schema-consistent will not be remembered. Examples are specific (e.g., the customer ordered lamb chops) or unique (the customer ordered kangaroo liver) schema-consistent events.[2]

Was Bartlett's schema anything like an underlying sequence of events or actions? Bartlett's (1932) discussion of the relationship between schematic functioning and remembering (pp. 202–208) suggests that it was not. According to Bartlett, the schema that guides the comprehension of input events or that generates the order of recall items is not itself sequential in structure: it operates not simply as a sequence of individual items "coming one after another, but as a unitary mass" (p. 201). At the time of remembering, this broad and nonsequential schema enables the individual to "rove more or less at will in any order over the events" (p. 203) and to produce the order in which items should be arranged for recall.

The structural schema theories just discussed have diverse origins (computer models, associationism, linguistic theory) and use different metaphors or analogies (the computer program, the network, the sentence), but they all

[2]Surprise-ending stories present a serious problem for the SP+T hypothesis. Why don't people treat the surprising events as merely inconsistent or irrelevant? Structurally, the surprising events are at least as consistent with the pre-surprise event structure of the story as are comparable no-surprise events. One might assume that irrelevant or inconsistent events are likely to be remembered to the extent that they receive active (or conscious) attention by the individual. In the flip-flop that occurs in the surprise-ending story, two dramatically different interpretations of the story are involved. It is unlikely that, upon encountering the surprising events, the reader goes back and pays conscious attention to story events in order to reinterpret them one after another in terms of the post-surprise perspective. How can we "describe the somewhat instantaneous reshuffling involved in the comprehension of this [kind] of story" (Iran-Nejad, 1980, p. 27)? Any answers that the structural schema theory might offer to these questions are still as unknown as they were when Iran-Nejad (1980) raised them two decades ago.

view knowledge construction as the retrieval and instantiation of pre-existing long-term memory schemas. Structural schema theories also tend to suggest that learning cannot occur in the absence of prior schemas and/or external input; and, consequently, it is often necessary within these models to postulate innate knowledge structures to account for learning at early stages of development. In addition, they all view background knowledge as a storehouse of a vast number of static structures; they all consider the schema to be a monolithic building block of long-term memory; they all use processing concepts (i.e., search, find, retrieve) compatible with the long-term storage metaphor; and they all assume that the most important goals of psychological research must be understanding how knowledge is organized in long-term memory and how isolated schemas are retrieved and instantiated.

Although the differences among the three versions of structural schema theory are also substantial, it is important to note that these differences do not make them incompatible. In fact, the three approaches may be viewed as complementary in that each area seems to address a different aspect of cognition. Neisser's computer metaphor stresses the information processing aspect; the network theory concentrates on the overall structure of long-term memory; and the script theory/story grammar approach captures the sequential aspect of human knowledge. The most severe problem facing the structural schema approach concerns learning. In its extreme form, this problem is illustrated by the fact that the program analogy led Neisser (1976) and Rumelhart (1980) to assert that people ignore all information other than schema-consistent information. As already discussed, network theories and script theories also face similar problems in dealing with nongeneric schema-consistent information. In particular, it was shown that the script theory cannot handle novel but schema-consistent information and the way it handles schema-inconsistent information is arbitrary.

What we have discussed so far are some of the problems the structural schema approach encounters with regard to what might be called *fact learning*, problems that have to do with whether or not the schema being instantiated contains suitable slots for the available input information. There is, however, the even more severe problem of how people manage to acquire new, more complex, or different schemas than the instantiation schema with which they begin their learning (Bereiter, 1985).[3] This problem seems to be

[3]To translate Bereiter's (1985) learning paradox into the problem surprise-ending stories present for structural schema theory, we must ask how people manage to create the post-surprise schema that is so different from the instantiated pre-surprise schema whose event connections are already firmly in place. How can people uninstantiate one schema in order to instantiate another with the same event? It was questions such as these that led Iran-Nejad (1980) to the conclusion that schemas must be viewed as transient structures, thereby abandoning the notion of long-term memory schemas altogether.

a consequence of the more general assumption in cognitive psychology that human beings have active control over their learning. It arises not because the active control hypothesis is incorrect, but because active construction is often viewed as the one and only source to regulate learning in novel situations (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977).[4]

The problem can be illustrated in the context of Neisser's (1967) dinosaur reconstruction analogy of active construction in the information processing system (IPS). There are three components to the analogy. Analogous to the paleontologist as the agent of reconstruction is the internal executive as the agent of active knowledge construction in the IPS. Analogous to the procedure (or the "recipe" for dinosaur reconstruction) that the paleontologist follows are long-term memory schemas, which are static and passive. And, finally, analogous to the particular raw materials (bone fragments, etc.) used in dinosaur reconstruction, there is the concrete information content, which is also static and passive. This analogy suggests that the only component that actively engages in the construction process is the central executive. The other two components are static and passive.

Neisser's (1967) view of active construction continues to be widely embraced today. For example, in the introductory chapter of a book on learning, Andre and Phye (1986) state that "the executive is that component of our memory system that keeps track of what information is being processed and controls the flow of processing to determine which activities occur and which processing components receive system resources" (p. 9). Given Neisser's (1967) view of active construction, it is difficult to see how an individual can construct a schema more complex than the schema that guides the process of construction. Thus, "although this 'constructivist' view of learning and development has a great deal of intuitive appeal and empirical support, it is in trouble theoretically" (Bereiter, 1985, p. 201) because it faces a learning paradox that continues to defy solution. We will return to this point after discussing Bartlettian functional theory.

Bartlett's Functional Schema Theory

There are several reasons to view Bartlett's (1932) theory as fundamentally different from the accounts described above. First, as already shown, he rejected several of the basic assumptions common in modern constructivist theories. Second, the majority of the concepts now common in the structural schema literature were seldom used by Bartlett. Third, Bartlett's own concepts (e.g., turning round upon one's schema) have generated considerable confusion among structural schema theorists. And finally, it can be shown that Bartlett's theory has its own origins and assumptions and that many of the structural interpretations commonly made of Bartlett's ideas are, in fact, incompatible with his theory.

[4]This would be analogous to the president of the United States allocating personal attention to every change that ought to occur in the country. The alternative, of course, is for the individual citizens to regulate changes locally and for the president to only delegate attention to those local events (see Iran-Nejad, 1990). This is the essence of distributed self-regulation that can be only dynamically regulated (Iran-Nejad and Chissom, 1992).

Pre-Bartlett Structuralism and Functionalism

Neisser's (1967) program analogy spawned the most plausible and certainly the most productive form of structuralism — but structuralism was by no means a new approach. The nearly exclusive reliance on direct analysis of mental products (software) mandated by the program analogy was also the hallmark of nineteenth-century structuralism. Ironically, it was Neisser (1976) himself who drew attention both to this similarity between modern and pre-Bartlett structuralism and to the undesirable consequences of the direct structural analysis approach. He stated that "the study of information processing has momentum and prestige, but it has not yet committed itself to any conception of human nature . . . its basic assumptions go little further than the computer model . . . [and] are surprisingly like those of nineteenth-century introspective psychology, though without introspection itself" (pp. 6–7).[5]

Historically, two alternatives to direct structural analysis of mental products have been proposed. Gestalt psychology (Wertheimer, 1945), cited often as one of the predecessors of the modern structural schema approach, rejected direct analysis of mental structures arguing that the properties of the whole are lost in the course of its analysis into parts (Boring, 1942). The other approach that opposed direct analysis of mental objects was the functional perspective (Angell, 1907; Dewey, 1896; Head, 1920). For example, referring to the structuralism of Wundt (1874) and Titchener (1898), Angell stated that in their hands "mental life tends to fall apart, and when put together again it generally seems to have lost something of its verve and vivacity. It appears stiff and rigid and corpse-like" (1907, p. 74). Unlike pre-Bartlett or modern structuralists, functionalists did not assume that mental structures pre-existed as static long-term memory. Like Bartlett (1932), Angell, for instance, explicitly rejected the long-term storage metaphor stating that no matter "how many metaphors we may summon to characterize the storage of ideas in some hypothetical deposit chamber of memory, the

[5]Neisser's acknowledgement that his information processing theory flourished at the expense of "any conception of the human nature" is essentially the same as Iran-Nejad's (1980) claim described in footnote 1 about the story grammar approach having flourished at the expense of those very human characteristics that make stories what they are.

obstinate fact remains that when we are not experiencing a sensation or an idea it is, strictly speaking, non-existent" (1907, p. 65).

Pre-Bartlett and Bartlett's functionalism were similar not just in their rejection of direct structural analysis or long-term memory metaphors, but also in their opposition to the ideal of simplification by isolation. Dewey's (1896) objection to the notion of the reflex arc and Bartlett's (1932) objection to the study of nonsense syllables are prime examples. Dewey stated that the so-called reflex arc does not function in isolation as a patchwork of discrete parts connected by a string of associative links; rather, every reaction is an "uninterrupted, continuous redistribution of mass in action" (1896, p. 364).

Bartlett's Schema as Physiological and Functional

Bartlett (1932) explicitly identified his approach as being functional and physiological: "believing as I do that psychology in its experimental aspects is a biological science, I have endeavored throughout to adopt a strictly functional point of view" (p. vi). Interestingly, Head (1920) was the only functionalist whose influence Bartlett directly acknowledged, and Bartlett rarely discussed the work of early structuralists in any detail. However, Bartlett viewed his approach as being in stark opposition to associationism which he criticized extensively. Before accepting Head's schema theory, Bartlett made two qualifications. The first qualification is Bartlett's (1932) strong rejection of the notion of a mental warehouse. In his writings, Head (1920) used the phrase "storehouse of past impressions;" and this was one aspect of Head's theory that Bartlett carefully disclaimed. The second qualification reflects Bartlett's unwillingness to allow a categorical distinction between what is conscious and unconscious. Head, when discussing how no change can ever occur in isolation, stated that impulses do not "enter consciousness" as single events; rather, every change, before it rises into consciousness, combines with the ongoing schema "outside central consciousness" (pp. 605–607). Rejecting the categorical separation between what is conscious and unconscious, Bartlett found such expressions as "into" and "outside" consciousness perplexing. With these qualifications made clear, Bartlett essentially adopted Head's functional schema theory.

Like all functionalists, Head (1920) attributed a central role in mental functioning to ongoing awareness — awareness and physiology were the foundations on which he built his definition of the schema. He maintained that moment to moment functioning of the nervous system was responsible for continued updating of peripheral and focal awareness, forming "organized models of ourselves which may be termed 'schemata'" (1920, p. 607). Referring specifically to postural ongoing schemas, Head stated that "anything that participates in the conscious movement of our bodies is added to the model of ourselves and becomes part of these schemata" (p. 606). He emphasized the term "anything" by stating that "a woman's power of localization may extend to the feather in her hat" (p. 606). It was in this sense, of cognition built on the foundations of physiology, ongoing activity, and awareness, that Bartlett (1932) adopted Head's notion of schema.

Thus, Bartlett's (1932) schema was an ongoing organization that could neither be isolated as an elemental monolith nor stored away statically as a program-like entity. It was a global "model of ourselves" emerging out of the ongoing functioning of the nervous system as an integrated totality and expanding continuously from within to the world around us. This is the essence of an approach that urges an explanation of mental phenomena in terms of the functional properties of the brain. It is important to keep in mind that Bartlett chose to adopt Head's, a neurophysiologist's, notion of schema as his theoretical weapon for arguing against (a) behaviorists' tendency to over-emphasize stimulus control and (b) the ideal of simplification by isolation characteristic not just of the work of Ebbinghaus, but also of "the bulk of experimental psychological work on perceiving, on imaging, on feeling, choosing, willing, judging, and thinking" (Bartlett, 1932, p. 6).

The failure of the term schema to capture these crucial aspects, its inherent static connotation, and its potential for misuse were sources of concern that Bartlett (1932) repeatedly mentioned (pp. 201, 203, 311). He noted that the term schema "does not indicate what is very essential to the whole notion, that the organized mass results of past changes . . . are actively doing something all the time; are . . . carried along with us, complete, though developing from moment to moment" (p. 201). To capture these ongoing and global aspects, Bartlett sometimes used the expression "schema-of-the-moment" (pp. 202, 203, 214).

For Bartlett (1932), the schema-of-the-moment was a coherent or "organized mass rather than . . . a group of elements each of which retains its specific character" (p. 197). He did not elaborate on the phrase "organized mass" however; although he clearly suggested that he had in mind something similar to what people like Thomas Brown (1820) and John Stuart Mill (1843/1965) meant when they used the term "combination." In an associative cluster, the elements retain the properties that reveal their identity. In this sense, an associative collection is analogous to a physical mixture as opposed to a chemical combination. Out of the combination of oxygen and hydrogen emerges a compound that is neither oxygen nor hydrogen, with characteristic physical properties that identify it as water but no longer as the original elements. By contrast, out of the mixture of oil and water, nothing emerges that is not oil or water. By the same token, the mental combination (or the schema) that emerges is different "in kind" from the collection of elements that create and uphold it (Jenkins, 1974).

But unlike a chemical combination which is relatively permanent, Bartlett's schema was inherently *transient* and ongoing (see Iran-Nejad, 1980) ". . . since its nature is not that of a passive framework or patchwork, but of an activity, it can be maintained only if something is being done all the time" (Bartlett, 1932, p. 203). Recall that Bartlett's rejection of the schema as a "passive framework or patchwork" suggests a perspective which contrasts diametrically with the one implied by the notion of schema shown in the second component of Neisser's dinosaur analogy.

Finally, Bartlett's (1932, 1935) schema, like Head's (1920), was discussed as a dynamic mass of psychological and physiological activity. It was ongoing awareness created and upheld by a mass of ongoing physiological activity. Bartlett suggested that two types of activity contribute to the evolution of the ongoing schema. The first occurs "on a basis of purely physical and physiological determinants" (1932, p. 208) outside the individual's active or deliberate control. The second type is active, is mediated by awareness, and occurs after the person discovers a way to "turn round upon" the ongoing mass and manages to "get to know" and control its components. It is in terms of these two types of constructive activity, and not by filling the instantiation slots in a passive long-term memory schema, that background knowledge influences perception, comprehension, and remembering.

Unexplaining Bartlett's Theory

There is evidence that Bartlett's (1932) schema theory represents a functional approach different in kind from modern structural schema theory (Iran-Nejad, 1980). The differences between the two approaches suggest that (a) problems associated with the structural schema approach do not necessarily apply to Bartlett's schema theory, and (b) recent claims about flaws in Bartlett's view may be an artifact of the application of a structural perspective to his functional theory.

The nature of schema. In structural schema theory, cognitive schemas consist of unconscious relations and processes. As a result, structural interpretations suggest that Bartlett's schema is an unconscious mental structure. For instance, Neisser (1967) identified four levels of theoretical analysis: physiology, unconscious schemas, contents of consciousness, and overt behavior. Bartlett's cognitive psychology, Neisser argued, was about unconscious long-term memory schemas whose existential status had always been uncertain until structural cognitive psychology literally discovered the program-like nature of schemas with the advent of the computer metaphor. More recent structural interpretations of Bartlett's theory have essentially reached the same conclusion. For instance, Brewer and Nakamura (1984) discussed Bartlett's theory and argued that "the hypothesis that schemas are complex unconscious knowledge structures is one of Bartlett's major contributions" (p. 121).

Indeed, some of Bartlett's (1932) statements, if viewed from a structural point of view, may be construed as suggesting that schemas are unconscious. As Brewer and Nakamura (1984) have noted, Bartlett stated that "every day, many times over, we make accurate motor adjustments in which . . . the [postural] schemata are active, without any awareness at all, so far as the measure of the changing postures is concerned" (p. 200). However, from a functional point of view, we can infer that Bartlett was concerned here not with an all-or-none definition of schemas as unconscious memory structures but with the notion that unintentional adjustments, or "unwitting alterations" as he called them, occur all the time in ongoing schema.

Not only did Bartlett (1932) not view schemas as unconscious structures but he, like Head, equated cognition with awareness or at least strongly suggested that there is no cognitive material without it:

> What I have agreed to call "reactive significance" may be present on a purely physiological level, but as soon as ever the reacting subject, or organism, becomes aware of the material with which his reactions deal, there is meaning. The stage has been prepared already for the organization of such material into specific settings. (p. 237)

Here Bartlett makes awareness, which arises out of purely physiological activity, a prerequisite for establishing meaning — meaning emerges with the emergence of awareness. Furthermore, he claims that with the emergence of awareness (or meaning), the stage is set for cognitive material (e.g., mental imagery) to organize into "specific settings" (i.e., particular schemas).

Active construction and connection-based automaticity. In modern schema theory, constructive processes refer to retrieval, instantiation, and modification of generic long-term memory schemas. Retrieval may be active and occur top-down under the control of the individual organism represented internally by a central executive. It may also be automatic and occur on the basis of pre-established between-schema connections. Similarly, schema instantiation can be active under the selective control of the organism or automatic on the basis of within-schema connections. Thus, the schema either serves as a plan for the processing (or assimilating) of incoming information for which there are pre-existing slots (or variable nodes) in the schema, or the schema serves to determine the default contents of those slots for which no explicit incoming information is available. Schema modification occurs when the incoming information does not readily fit the slots but can be accommodated under the active control of the individual organism.

Structural schema theorists generally assume that this is the sense in which Bartlett used the term "construction." Brewer and Nakamura's (1984) recent discussion of Bartlett's theory can be used to illustrate this point. These

authors distinguish between two versions of Bartlett's theory, both of which imply schema storage, retrieval, and instantiation, but to different degrees: a pure reconstructive version which allows only the storage of generic, long-term memory information and a partial reconstructive version which allows the storage of both generic and episodic information.

According to the pure reconstructive version, if someone, for example, "goes into an office that they have never been in before, the information about that office will be integrated with the individual's established office schema and will modify that schema to some extent" (Brewer and Nakamura, 1984, p. 124). Since the only thing that is subsequently committed to long-term memory is the generic information, the pure reconstructive theory "accounts nicely for the recall of generic schema information (e.g., typewriter, chairs) . . . [but it] cannot account for the recall of specific nongeneric information about the room (i.e., that the typewriter was an Underwood Standard or that one of the chairs was made of plastic)" [p. 124]. Brewer and Nakamura (1984) also stated that the pure reconstructive version of Bartlett's theory is the one that Bartlett "presents formally when he is describing the memory process in abstract theoretical terms" (p. 125). However, when Bartlett is discussing his actual empirical findings, he reverts to a partial reconstructive theory, which assumes that recall is a joint function of a generic long-term memory and an episodic long-term memory.

The pure reconstructive theory is a structural schema theory in its extreme form and, as Brewer and Nakamura (1984) noted, it is obviously in error. In fact, strictly speaking, such a theory would hardly be a general theory of memory at all. A person walks into an office, retrieves and instantiates a generic schema, and walks out like someone suffering from amnesia, with nothing more than the same generic long-term memory schema, unless something in that office causes the individual to actively modify the generic schema, in which case the person would walk out with nothing more than a modified generic schema.

Given the functional nature of Bartlett's theory, however, the interpretation changes. First, Bartlett (1932) argued that schemas can exist only as long as, and to the extent that, they are being upheld by the ongoing physiological and psychological materials. He did not allow long-term storage of schemas at all, generic or episodic. Second, nowhere in Bartlett's discussions can direct evidence be found for the type of dichotomy between generic and episodic information that the partial reconstruction theory suggests, although there is much indirect evidence that may be used in support of the structural hypothesis. Third, as already noted, Bartlett often stated that the goal of his theory was to explain how schemas are formed afresh every time they are used and not how they are retrieved and instantiated. Fourth, Bartlett (e.g., 1932, pp. 172–173) often argued that his data pointed against long-term preservation of

generic information. And, finally, with regard to active construction, Bartlett explicitly rejected the prior existence of a unitary (homunculus-like) central executive or "some intangible and hypothetical persisting 'self,' which receives and maintains innumerable traces, re-stimulating them whenever it needs" (p. 213). If these arguments are correct, not only is the structural interpretation less likely than a functional view, but the problems Brewer and Nakamura (1984) attributed to Bartlett's theory are the unique result of the structural interpretation.

Active construction in Bartlett's schema theory. In various places in his book and especially in the section where he directly discussed his constructive theory of memory (pp. 202–208), Bartlett (1932) repeatedly uses the phrase "turning round upon one's schemas." While noting that many readers have found this expression unintelligible, Brewer and Nakamura (1984) state that Bartlett used the phrase to explain "how an individual produces a specific memory representation from a generic schema representation" (p. 124). Once again, from the perspective of a structural theory, this interpretation makes good sense: Bartlett's theory allowed long-term storage of generic information but not of episodic information; therefore, he used the expression turning round upon one's schema as a way of describing how remembers might fabricate the episodic information they have not stored using the generic information they have stored.

From a functional perspective, however, it makes more sense to assume that Bartlett (1932) was concerned here with the more fundamental problem of how an organism, with no homunculus-like executive, can gain active or executive control over the nonexecutive components of its ongoing schema-of-the-moment. Such active construction is necessary, for instance, during recall because the ongoing schema tends to operate en masse, rather than sequentially, whereas during recall, events must be placed in a particular sequential order. Thus, something above and beyond "schematic determination" must operate. The ongoing schema "must become, not merely something that [automatically or spontaneously] works the organism, but something with which the organism can [actively] work" (p. 208).

Remembering. The main hypothesis that Bartlett derived from his theory and tested was that recall is inherently inaccurate. Like his theory, Bartlett's (1932) evidence has also been a source of controversy (Alba and Hasher, 1983; Royer, 1977; Spiro, 1977). Some authors have suggested that inaccuracies of the type Bartlett reported may have simply resulted from guessing (Gauld and Stephenson, 1967). Others have interpreted the notion of reconstruction as being synonymous with the incidence of gross inaccuracy in recall (Gomulicki, 1956) and have cited the fact that recall is often accurate (Howe, 1970; Kay, 1955) as evidence against Bartlett's theory (Zangwill, 1972). Recently, Spiro (1977, 1980a) has made a convincing case for the

proposal that Bartlett's theory predicts both accurate and inaccurate recall under specifiable conditions.

Toward a Biofunctional Theory of Remembering

The Problem of Integration

When we try to understand structural schema theory in some depth, we discover that the different components that the model suggests for the cognitive system defy integration. There is the abstract schema, which is a static pattern consisting of variable nodes (or slots) and connections or a recipe-like set of instructions. There is also the external information that enters the system. The agent of control that applies the schema to the input is the conscious individual represented internally by some homunculus-like executive component. The string of input from outside decays quickly and irrevocably unless it is consciously attended to by the individual person. The input that receives conscious attention cannot be learned unless it can be tied to some preexisting schema. Thus, in structural schema theory, the executive component, the schema, and the input from outside are essential as a group for any learning to occur at all in the system. How these three components combine into a working system, however, is currently a mystery even from the perspective of the computer metaphor.

The nature of the problem of integration can be illustrated in terms of the metaphor that captures well the knowledge construction aspect of structural schema theory, namely, the building construction analogy. One severe constraint is that the three system components — the builder (analogous to the executive component), the blueprint (analogous to the schema), and the raw construction material (analogous to the input from outside) — are so dramatically different in nature that they belong in three different realms of existence. For instance, the abstract blueprint or recipe belongs in the nonphysical or at least symbolic world of form, mind, or metaphysics, which is a mode of existence dramatically different from the one in which the nonsymbolic building material can exist. Since it must be abstract enough to be applicable to all instances of a given type of building, a symbolic blueprint cannot refer to the (nonsymbolic) wooden framework of a particular building because it would not be general enough to be applicable to buildings of the same sort built out of steel frameworks. Similarly, as an animate being, the builder is in a different realm of existence from the inanimate building material and the abstract blueprint. It is not clear how the integration of components as dramatically different as these can be brought into the realm of scientific investigation. Any reductionist pursuit of the three components, even together as a set, runs the risk of only yielding results that might be completely irrelevant to the integrated system.

During the 1960s, a ray of hope emerged for solving this problem of integration in the computer metaphor. A schema came to be viewed as a set of (symbolic) instructions (or a recipe) for the processing of input, just as a computer program is a set of (symbolic) instructions for data processing (Neisser, 1967). Not all human knowledge, however, can readily and adequately be transformed into symbolic instructions. Blueprints for building construction, for example, come in analog or pictorial form. Instructions, on the other hand, no matter how voluminous, detailed, and articulate, simply cannot represent what a diagram can portray.

Two assumptions about the relationships among separate system components in structural schema theory are noteworthy. A slot-filling assumption relates the abstract schema and the concrete input — the schema contains slots that are filled or instantiated with the raw content from outside or from long-term memory stores. This is what knowledge construction means in structural schema theory; it is relating the input from outside to an abstract schema from long-term memory. The second is an active construction assumption which implies that the slot-filling constructive activities are regulated by the individual person, just as the builder serves as the sole agent of construction in building construction.

But neither the slot-filling nor the active construction hypotheses can satisfactorily solve the problem of integration. Consider the inherent dichotomy, suggested by the structural schema theory, between the abstract schema and the particular content. Alba and Hasher (1983) reviewed the evidence bearing on the integration of the abstract and the concrete. They concluded that mental structures are much richer and more detailed than modern schema theory can allow. Anderson (1984) examined the issue of "whether schema theory can give an adequate account of the large amount of detail that people get into their mental representations during most acts of comprehension" (p. 7). He argued that it is difficult to see how the generic long-term memory schema underlying a concept such as "holding," for example, can enable the comprehender to actively generate rich scenarios as different as those that are needed to interpret the utterances "the rock held the door," "the container held the cola," and "the scientists held a conference." After a convincing reanalysis of the data from his research on schema theory, Anderson (1984) concluded that people use words "as [symbolic] instructions to locate specific cases [and not abstract schemas] in memory" (p. 8).

What Anderson (1984) called the "strong schema theory" and successfully challenged was, of course, Brewer and Nakamura's (1984) pure reconstructive theory. Anderson, like Bartlett, rejected the prior existence of generic long-term memory schemas, stating that much of what "passes as general knowledge is actually produced as needed by retrieving specific cases and making calculations based on them" (p. 8). But Bartlett's theory was more

radical; it allowed no long-term storage of static traces at all — specific or general:

> In the past the problems have been concerned mainly with how millions of individual traces can persist in the mind or in the nervous system . . . . For us, however, the problems fall into two main groups. First, how are the schemes, the organised patterns of psychological and physiological material formed? . . . Second, what are the conditions and laws of construction in the mental life? . . . These are urgent psychological problems, not outside the experimentalist's scope. (Bartlett, 1935, p. 225)

What Bartlett might be suggesting here, although we cannot be sure, is that the integration of the psychological and physiological aspects of human mental functioning (or a solution to the mind–brain problem) is no longer outside the scope of experimental psychology (see Iran-Nejad, 2000, this issue). The solution involves understanding how schemas are formed and it requires understanding the conditions and laws of construction in mental life and not the processing and storage of mental products. Bartlett (1932) postulated two kinds of constructive processes, one that occurred on the basis of "purely physical and physiological determinants" (p. 208) and resulted in the (spontaneous) formation of schemas, and one that operated when "the organism discovers how to turn round upon its own 'schemata'" (p. 208) and when the individual develops the capacity to control them. In this way, perhaps Bartlett suggested that both mental schemas and executive control are consequences of the physical and physiological laws of construction.

Two Sources of Self-Regulation

Bartlett (1932) did not elaborate on exactly what laws of construction are responsible for schema formation and for the organism discovering a way of executively controlling its own schemas by turning round upon them. However, he did describe the constructive processes involved enough to set them apart from similar constructive processes implied by structural schema theory. He suggested that an important aspect of this interaction is the principle of *effort after meaning*. "The attempt to connect something that is given with something other than itself" (p. 227) is a process characterized by a "preliminary check, the struggle to get somewhere, the varying play of doubt, hesitation, satisfaction and the like, and the eventual building up of the complete story accompanied by the more and more confident advance in a certain direction" (pp. 204–205).[6]

[6]Here, Bartlett (1932) is suggesting that his notion of effort after meaning is guided not by any finished structures, rules, and procedures. Rather, central to Bartlett's notion are the very human characteristics (i.e., uncertainty, doubt, hesitation, satisfaction, curiosity, surprise, suspense, and the like) whose abandonment resulted from the popularity of the story grammar approach that favored instead pre-established structures and rules.

Whereas structural schema theory presupposes the prior existence of an executive control structure and mental schemas, Bartlett (1932) suggested that both of these emerge out of the interaction of physiological and psychological processes. Whereas the exclusive focus of structural schema theory is on the analysis of mental products, the focus of Bartlett was on understanding the laws of construction — maybe even those involved in the interaction of physiological and psychological processes. Therefore, whereas structural schema theory, by resorting to the computer metaphor, pushes us further away from considering the mind–brain problem, Bartlett's theory may even point to some of its major parameters.

Since Bartlett (1932), our understanding of the laws of construction in the mind–brain relationship has improved dramatically (Iran-Nejad, Clore, and Vondruska, 1984). A major aspect of this understanding has to do with the nature of internal sources of self-regulation (Iran-Nejad, 1990; Iran-Nejad and Chissom, 1992). Both Bartlett and traditional schema theorists assume one source of internal self-regulation: that the individual organism, represented internally by some sort of executive control process, actively regulates its own internal constructive processes. There is now much theoretical and empirical evidence for a second source of internal self-regulation. More specifically, the single-source theory of internal self-regulation maintains that executive internal control is the one and only internal source of control. The two-source theory maintains that there is dynamic, internal self-regulation in addition to executive, internal self-regulation (Iran-Nejad, 1990).

The two-source theory bears some apparent similarity to Schneider and Shiffrin's (1977) theory of automatic and controlled processes. There are, however, fundamental differences between the two approaches. Schneider and Shiffrin (1977) contrast internal control with automaticity (i.e., no control), which blindly follows the route of pre-established connections. In their model, novel construction is impossible without direct executive control, which is exactly what the building and dinosaur construction analogies discussed earlier imply. In building construction, there are prefabricated (or automatic) building blocks and new builder-established construction. There is no new construction in the absence of the human builder because the building materials, including prefabricated ones, are inherently static and passive. If construction materials were to be inherently dynamic and self-organizing, with appropriate functional and combinatorial properties, the need for the human builder and pre-established building blocks would not arise. Buildings, like trees, would naturally grow on the earth. Various elements of the dynamic materials would interact among themselves and combine into the complex whole that would constitute particular buildings. This is the basic assumption underlying the notion of dynamic self-regulation.

In other words, unlike buildings, trees are not dependent for their construction and development on human builders even though human beings can indirectly facilitate their growth. This is exactly how dynamic self-regulation works in brain functioning according to the two-source theory of internal self-regulation (Iran-Nejad, Marsh, and Clements, 1992) — dynamic self-regulation requires no executive self-regulation even though the former can be (indirectly) facilitated by the latter. Does tree growth follow pre-established blueprints? It is, of course, possible to describe the regularities in plant growth using a structural perspective (e.g., a prefabricated blueprint of a tree could be assumed to be stored in every seed). Alternatively, dynamic self-regulation that follows no pre-established blueprint can offer an equally plausible explanation. For example, because tree branches have the potential to grow, if suitably planted, into full trees, one would not want to conclude that every branch has a preformed representation of a mature tree stored in it. Instead, the dynamic self-regulation hypothesis only requires that the materials of which a branch is built have dynamic self-organizing properties to enable the various substances to interact, combine, and grow into a mature tree.

The notion of dynamic self-regulation suggests that there is more than one way to conceptualize automaticity. On the one hand, there is structural (or connection-based) automaticity, as described by Schneider and Shiffrin (1977). However, there is also functional automaticity that follows no pre-established connections and occurs without executive monitoring. Structural automaticity is rapid but difficult to alter and it is inapplicable in novel situations: "since an automatic process operates through a relatively permanent set of associative connections in the long-term memory store, any new automatic process requires an appreciable amount of consistent training to develop fully. Furthermore, once learned, an automatic process is difficult to suppress, to modify, or to ignore" (Schneider and Shiffrin, 1977, p. 2). Functional automaticity can be rapid or slow and is applicable to novel as well as old situations. The self-organizing subsystems of the nervous system can adjust their own activity without requiring executive monitoring to be applied to every change that must occur in the ongoing functioning of the system.[7] In this sense, the issue becomes not so much one of contrasting automaticity with control but of distinguishing between two different types of internal control: active or executive control and dynamic or nonexecutive control. Note that in structural automaticity, executive control comes first in the acquisition

[7]This is how the transient schema theory explains the flip-flop in perspectives that occurs during the comprehension of the surprise-ending stories (see footnote 4). In other words, it is dynamic self-regulation, unencumbered by any pre-established long-term memory connections, that regulates the massive reorganization that occurs for the post-surprise perspective to emerge out of the reshuffling of the story events (roughly speaking).

stage and clears the way for automatic processing by means of consistent practice. In functional automaticity, dynamic or nonexecutive construction is first and sets the stage for the emergence of executive control in the system.

The nature of executive self-regulation. How does a system consisting of subsystems capable of dynamic self-regulation manage to "turn round upon" its own subsystems and engage them in executive self-regulation? As already suggested in the tree analogy, organisms, like plants, are capable of dynamic construction. But, unlike plants, they are also capable of executive construction. In Bartlett's terms, plants are unable to turn round upon their branches or other internal self-organizing parts to control their activity. What happens beyond dynamic self-regulation, therefore, constitutes "a crucial step in organic development. It is where and why consciousness comes in [and] it is what gives consciousness its most prominent function" (p. 206). Bartlett said, "I wish I knew exactly how it was done. [And] on the basis of my experiments I can make one suggestion" (p. 206). His suggestion involved several important aspects.

The first aspect had to do with the emergence of awareness in the nervous system in the form of a global impression (an ongoing schema). Spontaneous schema construction regulated by dynamic control, as discussed above, may serve as the basis for this. The second aspect is the subjective discovery of emerging awareness. Together, these aspects may lay the foundation for the process of turning round upon the ongoing schema by producing an "attitude" (Bartlett's term for a schema with a particular orientation or direction based on background knowledge and prior experience) which organizes and gives direction to other ongoing schemas. It is on the basis of this attitude that executive control over dynamic schemas may be possible. The third aspect, executive self-regulation as it occurs during reconstructive recall, is also affected by this attitude as schemas recalled will each be reconstructed with this attitude, goal, or orientation in mind. Two other critical aspects of the turning round upon one's schemas are the individualization of schema components, and the within-schema sequential ordering that takes place at the time of recall. According to Bartlett (1932), "if 'schemata' are to be reconstructed after the fashion that seems to be demanded by the phenomena of recall, somehow we have to find a way of individualizing some of the characteristics of the total functioning mass of the moment" (p. 208).

In this fashion, functional schema theory and the two-source theory of internal self-regulation, although far from solving the problem of the nature of executive self-regulation, identify some of its conditions and parameters. More generally, as Bereiter (1985) has noted, "the self is itself a cognitive construction" (p. 214), a notion that has received extensive theoretical and empirical support in the work of Markus and her colleagues (Markus, 1977; Markus and Kunda, 1986; Markus and Wurf, 1987).

Dynamic self-regulation and the learning paradox. Bereiter (1985) formulated the learning paradox that the structural constructivist approach faces in terms of the following theoretical question: "How can the development of complex mental structures be accounted for by mechanisms that are not themselves highly intelligent or richly endowed with knowledge" (p. 205)? We believe progress toward a solution is possible along the lines discussed here and is suggested in the research of Bereiter (1985) and Markus (Markus and Nurius, 1986; Markus and Wurf, 1987). Of critical importance here are the assumptions that (a) the unintelligent system components to which Bereiter alluded must be capable of dynamic self-regulation, and (b) dynamic self-regulation is the prerequisite foundation for the emergence of executive self-regulation. The distinction between dynamic and executive internal control makes it possible to specify how sources of control might regulate different learning processes.

Comprehending, learning, and remembering. The hypothesis that the nervous system is multisource implies that the relative contribution of the different sources might change during comprehending, learning, and remembering, but the variety of the sources and the processes by which they make their contributions need not change. The implications of the multisource theory are far-reaching. First, it implies that the brain need not have comprehension-specific or memory-specific parts. Secondly, all the parts of the brain might contribute more or less to all brain functions including daydreaming, imagination, and problem-solving. These possibilities seem to be straightforward enough. Consider, for instance, the hand. It uses the same parts to grasp, write, paint, weave, and so on. Why should it not be the same with the brain? Why can the brain not use the same parts to comprehend, learn, remember, daydream, solve problems, and so forth? Nevertheless, the direction taken by traditional psychology and neuroscience has been almost exclusively toward identification of specific brain parts for specific functions or specific memories. As biofunctional theory implies, we cannot say that the brain stores a specific schema for the concept of restaurant just as the hand does not contain a blueprint for grasping. Similarly, we cannot say that a specific part or hemisphere of the brain is dedicated to language just as we cannot say that a specific part of the hand is dedicated to playing a song on the piano.

Summary and Conclusions

This paper began with the assumption that Bartlett's schema theory is fundamentally different from modern schema theory. A Bartlettian biofunctional theory was then developed which provided a theoretical framework for thinking about the nature of internal self-regulation and its role in knowledge construction. Ongoing schemas and sources of internal self-regulation were identified as the essential aspects of a cognitive system capable of knowledge creation and learning.

Like structural schema theory, the functional model attributes a critical role in learning to cognitive schemas. However, in Bartlett's schema theory, a schema is not an isolated, program-like, building block that provides instantiation slots for the storage of only schema-consistent information. Rather, it is "an attitude, or orientation, which we cannot ascribe to any localized physiological apparatus, but which has to be treated as belonging to 'the whole' subject, or organism, reacting" (Bartlett, 1932, p. 191). It is such a global schema that mediates the influence of background knowledge and provides an ongoing internal context for the creation of new knowledge.

A cognitive system equipped with only executive internal self-regulation is limited to the narrow realm of intentional learning. To be capable of widespread incidental (McLaughlin, 1965) and nonstrategic learning (Johnson and Hasher, 1987), the biofunctional system must also be capable of dynamic internal self-regulation. Then, new learning can occur under the immediate control of the active learner (intentional or strategic learning) or under the control of dynamic sources of internal self-regulation (incidental or nonstrategic learning).

In functional schema theory, learning is not the same as adding new mental units to a pre-existing storehouse of static long-term memory structures. Neither is it the establishment of new or stronger connections among pre-existing units. In biofunctional theory, learning is growth in the ability to take advantage of internal sources of self-regulation to (re)create ongoing knowledge and to do so with increasing efficiency, intuitive flexibility, and technical fluency. In this sense, learning amounts to an ever-evolving process of becoming, without any knowledge schemas ever "going frozen" into a long-term state of being.

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