Implicit Cognition and Spelling Development

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Intuitively it may seem that spelling involves explicit cognitive processes. However, a great deal of knowledge used during spelling is implicit, that is, we are not necessarily aware of the appropriate spelling convention. The goal of this paper is to address how existing theories of implicit cognition may contribute to the understanding of spelling development. The paper includes a review of the adult literature on implicit memory and implicit learning and how this literature may be applied to spelling development. Karmiloff-Smith’s (1986, 1992, 1994) multilevel model of representational redescription presents a framework from which to investigate the interrelation of implicit and explicit knowledge and how knowledge representation changes over time. Karmiloff-Smith’s model provides insight into observations of children’s spelling and can be used as a framework to better understand the development of children’s spellings.

Learning to spell is a process of abstracting information from print in order to produce accurate spellings. Existing theories of spelling development have addressed three types of information people use when spelling: phonological, orthographic, and morphological. Phonological information involves knowledge of how sounds (phonemes) map onto letters (graphemes) to produce accurate spelling. In English there is no direct one-to-one mapping of sounds to letters, for example, the /k/ sound can be represented by k, c, ck, or ch, depending on where it occurs in the word. As well, there are considerably more phonemes than graphemes in the language, for example, s may sound like /s/ or /z/, depending on where it occurs in the word. Orthographic information involves knowledge of how letters go together according to typical English convention. For example, an e at the end of a one-syllable word makes the preceding vowel long and double letters do not usually appear at the beginning of a word. Morphological information involves knowledge of meanings of words and their derivatives, for example, adding an -ed suffix to indicate past tense or knowing that the word signature is derived from

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the word *sign* even though the grapheme–phoneme correspondence is very different. Treiman and Cassar (1997) suggested that there is a complex interaction among phonological, orthographic, and morphological information even at very young ages.

As our spelling proficiency develops, we gain knowledge not only of the consistencies, but also of the inconsistencies of the language. The regularities of written words may be taught explicitly as spelling “rules” and may stay with us from childhood to adulthood. Such information may be retrieved from memory and applied to particular words during spelling. For example, when spelling the word *receive*, we may explicitly recall the orthographic convention, “*i* before *e* except after *c*.” Although such conventions may readily be applied during spelling, the rule may not be available explicitly to the speller. For example, when do we add *s* to pluralize a word (e.g., *bananas*) and when do we add *es* (e.g., *peaches*)? If spellers relied solely on explicit rules, the number of rules required to become a proficient speller would be overwhelming. Hanna, Hanna, Hodges, and Rudorf (1966) developed over 2000 phoneme-to-grapheme correspondence rules to represent a corpus of 17,000 words. Due to the complexity of written language, it is not probable that spelling development is determined by explicit learning alone.

If a great deal of knowledge used during spelling is implicit; that is, we are not necessarily aware and may be unable to state the appropriate convention, what is the role of this knowledge versus explicit knowledge in spelling development? How does information that is acquired implicitly become explicit, or does it? These are only a few questions that need to be answered by spelling researchers in order to understand how these complex representations of knowledge may interact as spelling knowledge develops. There is a great deal of information in the memory and learning literature that discusses the issue of implicit learning and retrieval. My goal is to review existing theories of implicit cognition and how these theories may inform us about spelling development.

Converging evidence and synthesizing experimental findings are important tools in psychology, but the task is rarely simple and straightforward. The subtleties of different theories and tasks used to measure identifiable cognitive processes add to the challenge of consolidating research. In reviewing the literature on implicit cognition it is evident that the idea of unconscious, unintentional, incidental, or automatic acquisition and retrieval of knowledge has been and remains to be a central topic in cognitive psychology. Retrieval issues have been investigated under the auspices of implicit memory, acquisition of new information under implicit learning. Implicit memory is generally addressed in priming studies and implicit learning in studies where participants learn a complex rule structure without conscious awareness. These two lines of research have implications for spelling. For example, implicit memory processes may be at work when spelling a word by analogy, that is, when comparing a word to the spelling of another word.
Implicit learning processes may be at work when learning complex orthographic structure. Recently, researchers have begun to look at the ecological validity of the implicit/explicit dichotomy (Schmidt, 1994; Kirsner, Speelman, & Schofield, 1993; Lockhart & Blackburn, 1993). In everyday life, people do not learn about their environment in either implicit or explicit ways, but rather there is a blending of the two (Reber, Kassin, Lewis, & Cantor, 1980). In the realm of everyday activities, nowhere has the role of consciousness, or unintentional acquisition of knowledge, been debated more than in the area of language skills. Ellis (1994), for example, argued that recognition and production of oral language rely on implicit processes, but meaning and mediational aspects of language acquisition rely on explicit processes. The distinction between implicit and explicit processes is important for understanding spelling acquisition as well. Intuitively, it may seem that written language could be governed by explicit processes, although undoubtedly, we are not explicitly taught how to write every word we produce. How does information acquired implicitly become explicit?

While the implicit memory literature deals with retrieval issues and implicit learning deals with acquisition of new knowledge, Karmiloff-Smith (1986, 1992, 1994) proposed a general cognitive model of how knowledge that may be acquired implicitly becomes explicit. Karmiloff-Smith provided evidence for her model, which she calls *representational redescription*, from children’s spoken language, general problem solving, and children’s drawings. If indeed it is a general cognitive model of how knowledge representation changes over time, perhaps Karmiloff-Smith’s model can provide insight to the domain of spelling development. Before reviewing this developmental model it is important to have a clear understanding of what is meant by implicit and explicit cognition. There is a very large body of literature that addresses the nature of implicit memory and learning in adults. Therefore, in order to grasp the issues of implicit cognition I first review the literature on implicit memory and implicit learning in adults and how it relates to spelling, and then turn to the developmental literature and the interaction of implicit and explicit knowledge.

**IMPLICIT MEMORY**

The term *implicit memory* refers to memory for information acquired in a previous episode that is expressed on tasks where participants are not required, and often are unable, to consciously recollect the previously studied information (Schacter, 1990). *Explicit memory*, by contrast, is intentional or deliberate recall of information acquired in a previous episode. Schacter (1987, 1990; Schacter, Bowers, & Booker, 1989) used implicit memory as a descriptive concept in order to facilitate classification of empirical phenomena. The term implicit memory was used to capture the difference in performance on recall and recognition tasks on the one hand and word completion,
lexical decision, and similar tasks on the other. The former class of tasks, referred to as direct memory tasks, involves explicit recollection of a prior episode and the latter class of tasks, referred to as indirect memory tasks, can be performed in the absence of conscious recollection. Differential effects in indirect and direct memory tests have been shown in amnesiacs, in normal adults, in children, and in older adults. There is evidence to support that at least some form of implicit memory functioning is seen in preschool children and remains intact throughout adulthood and into old age, even in the case of people who suffer from amnesia. On the other hand, explicit memory develops rapidly during preschool and school years, remains stable in adulthood, and declines in old age or in cases of amnesia (see Roediger, 1990a; Schacter, 1987).

Theoretical Issues

Although research on implicit and explicit memory provides relatively consistent results, there are diverse theoretical opinions regarding these results. There are two general classes of theory to account for the differential effects of indirect and direct memory tasks: multiple memory systems approaches and processing approaches (Roediger, 1990a).

Researchers who support the systems view explain the differences in performance on indirect and direct memory tasks based on two distinct memory systems in the brain that are relatively independent. Within this view, the two systems are sometimes equated with procedural and declarative memory systems, respectively. From the systems view, it is probable that spelling involves both the procedural and the declarative systems. For example, often when we are not sure of the spelling of a word, we may write various alternatives to see which one looks right. This could be viewed as activating the procedural system. When spellings are explicitly retrieved from memory, this could be viewed as activating the declarative system.

Researchers who support a process view propose that the differential effects of indirect and direct memory tasks reflect the operation of different memory processes. Such views focus on the nature of cognitive processes that mediate performance. According to one process view, dissociations that are observed between direct and indirect memory tests may reflect the operation of different cognitive procedures required by the tests themselves. This approach is similar to the encoding-specificity principle; that is, test performance is better when the retrieval context is similar to the encoding context. For spelling, this implies that different memory processes are activated depending on how the spelling of a word was encoded. For example, if the spelling was encoded by rote repetition, or mere exposure, this process view suggests that retrieval of the spelling may be a function of indirect memory processes. On the other hand, if the spelling of the word was encoded by conceptual processing, for example choices among homophones based on meaning, retrieval may be a function of direct memory processes.
Another process view relies on the distinction between integrative and elaborative processing. Integrative processing occurs when the stimulus activates other representations in memory as a unified whole. Integrative processing may occur when spellings are automatic and effortless. Memory for the spelling is activated as a unified whole. Elaborative processing occurs when the target item is related to other words, as required in a typical direct memory task. Elaborative processing is effortful, attention-demanding, and requires controlled processing. Elaborative processing may occur in spelling when the speller uses a phonetic, or sounding out, spelling strategy to thoughtfully produce an accurate phoneme-to-grapheme representation of a word.

Yet another variation of the process view is the spread-of-activation approach (Nelson, Schrieber, & McEvoy, 1992). Researchers who support the spread-of-activation approach propose that implicit memory is based on activation of preexisting memory representations. In indirect memory tasks, the study materials generally are familiar words that are represented in long-term memory well before the experiment and carry with them numerous preexisting associations. Activation occurs automatically; it does not rely on deliberate memory of contextual information that is part of the recent study experience. This approach accounts for differences in performance on familiar and unfamiliar words (Nelson et al., 1992). The spread-of-activation approach may explain how spellers use analogies to spellings of other words when attempting to spell an unfamiliar word.

Implicit Memory and Spelling

The implicit/explicit distinction in memory literature addresses properties of retrieval phenomena that involve unintentional and intentional recollection of previous episodes. Spelling, by the nature of the task, involves intentional recollection of information acquired in previous episodes. In this regard, the task involves explicit memory as earlier defined. However, implicit memory may also be involved with respect to information from past experience that unintentionally affects choices of spellings. The Dixon and Kaminska (1997) research suggests that even a single visual encounter with a word that is misspelled can cause the word to be misspelled in the future, even if the speller had spelled the word correctly prior to the encounter. For example, very early research reports showed that even when spellers could correctly produce a spelling, they might have difficulty choosing a correct spelling from a number of incorrect alternatives (Pintner, Rinsland, & Zubin, 1929), or they may not be able to correct incorrect versions of the same word (Nisbet, 1939). Brown (1988) and Jacoby and Hollingshead (1990) reported that exposure to either an incorrect or a correct spelling affected later spelling performance, resulting in subsequent incorrect and correct spellings, respectively. Jacoby and Hollingshead argued that the effect was mediated by implicit memory, suggesting that the priming by exposure to misspellings was an implicit process.
Dixon and Kaminska (1997) investigated whether exposure to misspellings had lasting effects and if it varied as a function of spelling proficiency. These researchers exposed adult good and poor spellers to incorrectly and correctly spelled words in a word-reading task and subsequently tested for the effect of exposure with a dictated spelling test either immediately or 1 week later. They reported persistent priming effects for at least one week in both good and poor spellers. These results are consistent with the persistent effects reported in the implicit memory literature. Dixon and Kaminska argued that because both good and poor spellers were equally affected, their research provides evidence that, at least in adults, poor spellers process detailed orthographic information in a similar manner to good spellers. This conclusion is contrary to existing spelling literature that suggests that poor spellers fail to encode the details of orthographic structure (e.g., Frith, 1980; Holmes & Ng, 1993; Link & Caramazza, 1994). However, Fischer, Shankweiler, and Liberman (1985) pointed out that not all orthographic structure is created equal. These researchers made a distinction between surface orthographic regularities that are frequently governed by phonetic features of the language (e.g., doubling the \( n \) in \( \text{thin} \) to make the past tense \( \text{thinned} \)) and abstract morphophonemic information that is governed by such factors as stress placement (e.g., doubling the \( r \) in \( \text{confer} \) to make the past tense \( \text{conferred} \), but not to make the noun \( \text{conference} \)). In the Fischer et al. research, good spellers performed better on words that required abstract morphophonemic knowledge than surface orthographic knowledge, whereas poor spellers showed no difference in their ability to spell the two types of words. Poor and good spellers may have been equally affected by priming effects in the Dixon and Kaminska research because their task tapped into surface orthographic features.

Frequently, spellers will make analogies to known words when attempting to retrieve a spelling from memory. There is considerable evidence suggesting that the analogies selected may be a result of implicit memory affecting subsequent spelling choices. Marsh, Friedman, Welch, and Desberg (1980) were one of the first spelling researchers to discuss children’s use of analogies in spelling. They asked children to spell nonwords that were analogous to exception words in English. For example, the nonwords \( \text{jation} \), \( \text{zol} \- \text{dier} \), \( \text{wength} \), and \( \text{cuscle} \) are analogous to \( \text{nation} \), \( \text{soldier} \), \( \text{length} \), and \( \text{muscle} \). Marsh et al. reported that although 7-year-olds did not spell the nonwords by analogy, about one-third of the 10-year-old participants managed to do so, and over half of the college students did so. Similarly, Campbell (1985) studied the effect of hearing a regular or irregular prime word prior to completing a nonword spelling task. Both children and adults were asked to write down any nonwords they heard in a mixed list of words and nonwords. Campbell reported that children whose reading age was less than 11 years did not show any bias toward previously heard words; children whose reading age was greater than 11 years showed the same pattern as college stu-
dents. In the latter case, the nonword /frit/ was more likely to be spelled freat if preceded by neat, but freet if preceded by feet. This research suggests that if analogy-use involves implicit memory, it may impact experienced spellers more so than beginning spellers.

The implicit memory literature suggests that there is little difference in priming effects across ages for young children. The Marsh et al. (1980) and Campbell (1985) studies on children’s use of analogies during spelling seem to contradict the implicit memory literature. However, these researchers did not establish whether the younger children were familiar with the spelling of the prime words. Goswami (1988) showed that when 7-year-old children were shown the spelling of “clue” words, such as beak, these beginning spellers used the prime words to spell analogous new words, such as peak.

Using Campbell’s (1985) lexical priming task, Nation and Hulme (1996) determined that the children were able to spell the prime words before proceeding with the experimental task of spelling dictated nonwords. Similar to Goswami’s results, Campbell reported that 6- and 7-year-olds used the prime words to spell nonwords; if children heard the prime word green, they were more likely to spell the nonword /grib/ as greeb than if they had not heard the prime word. Consistent with the implicit memory literature, the Goswami and the Nation and Hulme research shows that even beginning spellers are able to use analogies to familiar words when spelling real words and nonwords. Nation and Hulme concluded that use of analogies may be a by-product of connectionist models in which spellings of familiar words are generalized to novel words as a result of statistical relationships between the sound patterns and spelling patterns encoded in the system. This conclusion emphasizes the encoding aspect of analogy use, and therefore, is more akin to explanations of implicit learning which I will discuss in the following section. However, at this point I emphasize that when analogies are used it is not necessarily a deliberate process, which supports the role of implicit cognition in spelling.

In addition to evidence of priming effects and analogy, implicit memory may also be implicated in the effects of prior print exposure on spelling. Stanovich and Cunningham (1992) provided correlational evidence of the facilitative effect of prior print exposure on spelling ability. Ehri (1980) reported that when second graders were taught to read nonwords that contained silent letters, later attempts to spell these words, even if they were spelled incorrectly, frequently included the silent letters. The children in Ehri’s study often made phonologically plausible errors, but their misspellings support the hypothesis that implicit memory for orthographic structure of the word was at work. For example, if children were exposed to the nonword wheople, every misspelling began with wh, whereas, if children were exposed to the phonemically identical nonword weeppe, every misspelling began with we (Ehri, 1980).

We live in a highly literate society. Rarely a day goes by when we are
not exposed to print in some way. How is it that there are many people who do not learn to spell or have difficulty regardless of their exposure to the printed word? In order to understand spelling development, researchers need to address encoding as well as retrieval issues. Whereas implicit memory research investigates retrieval issues, implicit learning research investigates encoding issues.

**IMPLICIT LEARNING**

*Implicit learning* differs from implicit memory in that implicit learning generally refers to the acquisition of more complex information without awareness, whereas implicit memory deals largely with storage and retrieval issues (Reber, 1993). According to Reber (1993), implicit learning is an unconscious, passive process that results in knowledge that is unavailable to conscious awareness and not easily articulated. Most implicit learning researchers agree that the cognitive processes involved in implicit learning are not intentionally controlled, that is, there is no intention to learn, and implicit learning is incidental, that is, it occurs without conscious hypothesis testing (Buchner & Wippich, 1998; Neal and Hesketh, 1997; Seger, 1994).

Implicit learning is frequently discussed in conjunction with *implicit knowledge*. However, there is no clear definition of implicit knowledge in the literature. Implicit knowledge seems to be viewed as the product of implicit learning. For example, Reber (1993) called the kind of knowledge that results from implicit learning *tacit knowledge*. Dienes and Berry (1997a) asserted that in order for knowledge to be considered implicit, it needs to be inaccessible in some way. They suggested that knowledge can be inaccessible because it is not easily verbalized; for example, in implicit learning paradigms, people do not seem to have the ability to describe what they know, nor are they able to answer questions about it.

Although various tasks have been used to study implicit learning, they share common features. A typical research paradigm to study implicit learning includes a study phase where participants observe a set of stimuli constructed on the basis of a complex rule-structure and a test phase where participants are asked to solve a problem or make predictions in which they reflect the knowledge acquired. Participants are not told of the rule-structure and generally at test time do not freely report sufficient knowledge to account for the accuracy of their performance. Implicit learning is inferred to occur based on this differentiation between level of performance and lack of ability to verbalize the basis for their performance, reduced reaction times when compared to control conditions, or some evidence of having learned the underlying structure of complex stimuli. Implicit learning may be involved in spelling with regard to acquisition of spelling ability. Learning to spell involves abstracting structure and regularities from print and using this knowledge to produce accurate spellings at a later time. Implicit learning research addresses this ability to abstract rules and structure from complex environments.
Generally, researchers who study implicit learning have used normal adult participants. To a lesser degree, there has been some exploration of implicit learning in abnormal populations; psychotic patients, amnesics, and Alzheimer’s patients perform relatively the same as normal adults on tasks used to measure implicit learning, for example, artificial grammar learning (Dienes & Berry, 1997a; Reber, 1993).

Theoretical Issues

Although there has been an absence of global theoretical frameworks in implicit learning research (Buchner & Wippich, 1998), a key theoretical issue that has been addressed is the nature of the knowledge that is acquired. There are two general theoretical perspectives on the nature of implicit knowledge representation, the abstractive view and the episodic view. Reber (1993, 1997) supported the abstractive position, arguing that the complex knowledge acquired during an implicit-learning task is in a general, abstract form. An abstract representation is derived, but separate from the original episode. In this view, the abstraction contains little information concerning the surface features, or physical form of the stimuli. What is important is the structural relation among the stimuli (Reber, 1993). This view has considerable explanatory power, especially in regard to how participants can successfully deal with novel stimuli that are physically dissimilar and also how such knowledge can be transferred across stimulus domains. The abstractive view suggests that in a real-world task such as spelling, spellers are encoding the underlying rules and structure of words as they are exposed to them. However, one disadvantage of this view is the issue of abstraction itself. It is unclear how abstraction takes place; what is coded in the representation and what are the criteria for comparing abstract encoding of novel stimuli and previously stored abstractions?

Researchers who support an extreme episodic view argue that stimuli are encoded and stored as separate and accumulated instances or events and not as patterns and regularities among features. This view explains encoding-specificity effects; that is, performance is sensitive to the match between encoding and retrieval conditions (Vokey & Brooks, 1992). The episodic view can explain direct, automatic retrieval of spellings; words are encoded and stored as separate instances and can be retrieved quickly and effortlessly. The episodic view has an advantage over the abstractive view in that the process of storing exemplars is straightforward; there is no need to recode stimuli or deal with induction of patterns and structures. However, episodic models such as this are directly tied to the physical form of the input stimulus and hence are very inflexible. The episodic view cannot explain how we can produce reasonably accurate spellings of words we have never encountered, for example.

Dienes and Berry (1997a,b) rejected a clear dichotomy between abstract and episodic views and proposed that implicit knowledge includes an ab-
abstract component as well as sensitivity to the encoding conditions present during the initial study phase. Similarly, Seger (1994) proposed that there is no reason to expect that knowledge representations in implicit-learning paradigms could not be a combination of instantiation-linked rules together with noninstantiated abstract rules. There is considerable data to support all of the above views. As Reber (1993, 1997) suggested, people are flexible in their approaches to dealing with complex stimuli and are capable of establishing different forms of knowledge representations under different acquisition conditions.

**Implicit Learning and Spelling**

Learning to spell is a process of abstracting phonological and orthographic information from print and speech, and using this information in order to produce accurate and consistent spellings. Many researchers have investigated the development of phonological skills and how knowledge of phoneme–grapheme correspondence is correlated with spelling ability (Beringer, Abbott, & Shurtleff, 1990; Griffith, 1991; Juel, Griffith, & Gough, 1986; Lennox & Siegel, 1994; Liberman & Shankweiler, 1985; Treiman, 1993). Spellers of all ages and skill levels use phoneme–grapheme information when spelling (Bruck & Waters, 1990; Steffler, Varnhagen, & Boechler, 1999; Taylor & Martlew, 1990). Accurate knowledge of this sound–letter correspondence clearly differentiates spelling ability (Bruck & Waters, 1988; Muter & Snowling, 1997; Taylor & Martlew, 1990; Treiman, 1984; Waters, Bruck, & Malus-Abramowitz, 1988).

Most research on the relationship between spelling and phonological skill uses explicit measures of phonological awareness, such as phoneme segmentation, phoneme blending, or phoneme substitution tasks, that involve the ability to manipulate phonemic units within words. However, Ellis (1994) emphasized that there are implicit as well as explicit levels of phonological awareness. Stanovich, Cunningham, and Cramer (1984) found that explicit tasks that required participants to manipulate sounds in words (i.e., nonrhyming tasks), and perception of sound similarity of words (i.e., rhyming tasks), formed two separate, and uncorrelated, clusters of skills. Indeed, children’s first awareness of the sound properties of speech is implicit (see Ellis, 1994). Bradley and Bryant (1983) suggested children’s early experiences with nursery rhymes contributes to implicit phonological awareness. Ellis proposed that very early reading and spelling make use of this implicit phonological awareness and that as children gain experience with print, they develop explicit phonological awareness. In a longitudinal study, Cataldo and Ellis (1988) showed that implicit phonological awareness predicted reading and spelling in the first year of school, but not in the second and third years. Explicit phonological awareness predicted spelling from first to third year of schooling. Spelling researchers need to explore the relationship between implicit and explicit phonological awareness.
The development of orthographic knowledge has not been as well researched as that of phonological knowledge, perhaps because of the difficulty in separating phonological and orthographic information in typical spelling tasks. As well, there is lack of agreement concerning orthographic processing as a measurable construct (Wagner & Barker, 1994). There has been some debate among spelling researchers as to whether orthographic knowledge involves abstract rules based on linguistic patterns and regularities of the language, whole-word knowledge, called word-specific memory, or information about the statistical properties of letter combinations, such as frequencies and probabilities of how letters go together to form acceptable letter-strings in a language. Clearly, these are issues similar to those in the implicit learning literature concerning the nature of what is learned in an implicit learning paradigm; is it abstract rules based on surface features, episodic instances, or structural relations?

Orthographic knowledge is typically defined as the norms or conventions of how letters go together to form meaningful units in a language (Hanna et al., 1966; Perfetti, 1997; Sterling & Robson, 1990; Venezky, 1970). Venezky suggested that orthographic knowledge is used to establish orthographic images which include complex spelling patterns that match combinations of letters to sounds within words and syllables (e.g., eat, eight, sphere, shepherd) as well as common spelling patterns shared by sets of rhyming words (e.g., air, chair, hair, stair). Venezky’s view of orthographic knowledge is strongly connected to sound–letter mapping. In fact, Venezky pointed out that English orthographic rules often facilitate letter-to-sound conversion, as in the doubling of the final consonant of inflections (e.g., tap: tapped) and the insertion of k in picnicking. Gibson and Levin (1975) identified the unique contribution of phonological and orthographic information to word recognition. They expanded on Venezky’s idea that spelling units are related to an intermediate (morphophonemic) level and then to sound. Gibson and Levin suggested that the translation of letter strings into orthographic images of letter combinations requires two steps: the abstraction of the important graphic units, and the correspondences between the graphic units and sound (p. 179). For example, one requires orthographic knowledge of morpheme boundaries to translate the graphic symbol mishap into the morphophonemic level mishap; orthographic knowledge is necessary in order to understand that sh does not form a unit. Phonological knowledge is required to convert mishap to the word /mIshap/.

Others have questioned whether orthographic and phonological knowledge are so tightly knit. For example, Foorman and Liberman (1989) proposed that orthographic knowledge is the ability to analyze words into orthographic units with optional phonological recoding. Treiman and her colleagues suggested that orthographic knowledge includes information about spacing of words, orientation of writing, acceptable and unacceptable letter sequences, and the numerous ways that certain sounds may be repre-
sented with graphemes (Treiman & Cassar, 1997). Orthographic knowledge may involve information about complex sequences of letter patterns, such as the "ight in light (Ehri, 1986) or simple norms such as ck does not occur at the beginning of a word (Treiman & Cassar, 1997).

Gibson and Levin (1975) proposed that orthographic regularity means we have abstract rules that we use to predict future possibilities. Massaro, Ven-ezky, and Taylor (1979) suggested that these abstract rules are based upon both phonological and graphemic constraints, such as the nonoccurrence of initial consonant clusters composed of a voiced consonant followed by a voiceless one (e.g., dt). These authors pointed out that such orthographic rule-based approaches have not incorporated frequency measures, although these are not excluded by definition. Ehri (1980), on the other hand, proposed that orthographic images involve memory for whole words as a sequence of letters with a systematic relationship to the phonological properties of the word as well as to the syntactic and semantic properties of the word. She suggested that her idea of amalgamating knowledge of sound–letter combinations with semantic and syntactic properties of words is superior to perceptual recognition theories (cf. Gibson & Levin, 1975) because amalgamation allows for functional use of words as well as recognition. Ehri suggested that sounds play a crucial role in establishing orthographic images such that orthography is the representational system for storing sounds in lexical memory (p. 317).

Those who view orthographic knowledge based on statistical properties of letter combinations have investigated various sorts of structure that implicate word knowledge. For instance, McClelland (1976) and Mason (1975) have shown that single-letter positional frequency assists perception in letter-search and word-recognition tasks. Single-letter positional frequency refers to the frequency of each letter occurring in a particular position in a word. For example, the sum frequency of a occurring in first place, i occurring in second place, and r occurring in third place would affect the reaction time for identifying air as a real word in a word recognition task.

Orthographic structure has also been viewed in terms of interletter probabilities. Spoehr and Smith (1975) found that regular letter sequences, like blst, are easier to recognize than irregular letter sequences, like lstb. They define regular as any combination of letters that typically occurs in the English language. This notion of orthographic regularity is similar to the Gibson and Levin (1975) view that spelling can be thought of as a kind of grammar for letter sequences that generates permissible combinations without regard to sound (p. 294). Aaron, Wilczynski, and Keetay (1998) refer to this as a "rule-governed stochastic process." These researchers suggested that strings of letters within words have a systematic relationship with each other just as words in a sentence are governed by syntactical rules. They investigated whether word-specific memory was memory for the entire word as a whole, or a rule-governed stochastic process, that is, memory for frequently oc-
curring intraword letter patterns. They used deaf students who did not have access to phonological coding for processing written language and compared their performance to a control group of hearing children on a task that measured memory for pronounceable and nonpronounceable nonwords (e.g., *doof, kram, vs. dfoo, rmka*). The Aaron et al. rationale was that if memory for letter patterns was attributed to visual memory for whole words then the deaf children’s performance would be the same on both pronounceable and nonpronounceable nonwords. If, on the other hand, memory for letter patterns was based on stochastic memory then performance would be better on the pronounceable nonwords because these words were constructed from letter strings that one would typically encounter in the English language. Both the hearing and the deaf children correctly reproduced more pronounceable than nonpronounceable nonwords, which Aaron et al. took as evidence that stochastic memory for intraword letter patterns facilitates spelling more so than does rote visual memory. Aaron et al. (1998) viewed rule-based stochastic memory as a set of conventions that are abstracted as a result of repeated exposure to recurring letter patterns. The letter patterns are predictable because they conform to probabilistic contingencies of possible letter combinations in the language. They suggested that the rule-based component of word-specific memory is likely to be memory for bigrams and trigrams, which was confirmed by a qualitative analysis of spelling errors of deaf children. The errors of deaf children were due to intrusions of bigram and trigram letter units (e.g., *laugth, for laugh; trght for truck*).

Consistent with Gibson and Levin (1975), Aaron et al. (1998) separate orthography from phonology by making a distinction between stochastic rules about letter combinations and rules that specify phoneme-grapheme relationships. This clarification is important because many spelling researchers who discuss rule-based relationships are referring only to the latter. For example, dual-route models of spelling suggest that spellers use one of two routes during spelling: the direct route, or the indirect route (see Ellis, 1984; Barry, 1992; Seymour, 1992, for detailed accounts of dual route models). The direct route, as one might expect, involves direct retrieval of a known spelling from long-term memory. The indirect route involves applying phoneme-grapheme rules to map the individual sounds of a word to letters in order to produce a spelling. The former implies that spellers have a store of whole words in long-term memory that they are able to retrieve at will; the latter implies that spellers also rely on a set of rules based on how phonemes map onto letters. Sloboda (1980) disputed the notion that proficient spelling is a phonological-rule-governed procedure, and suggested that good spelling is a matter of remembering by rote the way individual words are spelled. He did not discount the possibility that poor spellers attempt to use phoneme–grapheme rules, but that often such an approach would result in inaccurate spellings, such as when attempting to spell phonemically transparent (e.g., *ebb*) or ambiguous (e.g., *knight*) words. Link and Caramazza (1994) review several studies using brain-damaged patients that support the inde-
pendence of phonological and orthographic knowledge. Some patients show preserved ability to use phonological skills but impaired ability to spell simple words. These patients produce phonologically plausible spelling errors (e.g., spelling chair as chare) when asked to spell simple words with ambiguous sound-to-spelling mappings. Other patients are unable to spell pseudowords but are able to spell words, including irregular words such as yacht. Link and Caramazza point out that one of the unanswered questions in spelling research is the nature of what is encoded in orthographic knowledge representation, a question that is also debated in the implicit learning research.

Whether one views orthographic knowledge as abstract rules governing the linguistic patterns of the language or information about the statistical properties of letter combinations, it is rational to assume that a great deal of this information is implicit. Many of the theoretical issues raised in the implicit learning literature have also been debated in the spelling literature regarding the nature of the knowledge representation. Perruchet, Vinter, and Gallego (1997) argued that whether knowledge that emerges from a learning experience is implicit or explicit is a meaningless question. They challenged the dominant view that implicit learning leads to implicit knowledge. Rather, they proposed that implicit learning changes the way in which new data are encoded. For example, Perruchet and Pacteau (1990) claimed that participants’ explicit knowledge of fragments in an artificial grammar were sufficient to account for grammaticality judgments in a typical artificial grammar task. Perruchet et al. (1997) suggested that participants who are exposed to artificial grammars, including frequent occurrences of certain letter combinations (e.g., VXT), no longer perceive these letters as separate entities, but as an increasingly familiar three-letter unit. In this sense, they argued that implicit learning changes conscious mental representations rather than leads to implicit knowledge. For spelling development, this implies that exposure to print changes the way we perceive words. As we acquire spelling knowledge we make continuous adjustments to our existing knowledge base, which in turn changes how we encode new information.

As Perruchet et al. (1997) suggested, to date there is not enough research to support their hypothesis; however, their recommendation is that all processes and mechanisms are unconscious and all mental representations and knowledge are conscious. Clearly, a simple dichotomy between implicit and explicit cognition is not sufficient to account for the data. Stadler (1997) suggested that the distinction between explicit and implicit knowledge is not as important as what people do with the knowledge if and when they become aware they have it.

It is evident that a great deal of research, both in the implicit learning and the implicit memory literature, has focused on differentiating implicit from explicit cognition. However, in everyday life people do not learn about their environment in either implicit or explicit ways, but rather the two complement one another. Learning to spell involves complementary processes of
implicit cognition when perhaps spelling regularities are acquired from exposure to print and explicit cognition when new spellings are explicitly taught, or perhaps an outside reference, such as a dictionary, is used to spell an unknown word. What components of the task are being encoded that facilitate implicit or explicit acquisition and retrieval? Theories of implicit memory and learning in adults do not adequately address the interrelation of implicit and explicit cognition. In order to investigate this interaction it is helpful to look at how implicit knowledge representation changes over time. How does knowledge acquired implicitly become explicit?

Much of a person’s knowledge about spelling begins to accumulate in early childhood. Therefore, to understand spelling development, it is essential to address the developmental aspects of implicit and explicit cognition. Compared to research with adult participants, there have been relatively few studies that directly examine implicit learning and/or memory in children. However, many researchers have expressed the need to investigate implicit processes from a developmental perspective (Durkin, 1994; Perruchet & Vinter, 1998; Reber, 1993; Roediger, 1990b; Seger, 1994). Karmiloff-Smith (1992) contended that there is not only this need, but a developmental perspective is essential to understanding human cognition in general. She proposed that understanding how knowledge changes over time will give clues to the nature of knowledge representation in the adult mind. An important issue in understanding the acquisition of new knowledge is the relation between implicit and explicit cognition. For this reason, Karmiloff-Smith’s model is compelling. She focuses on representational change over time, how implicit and explicit cognition work together in the acquisition and retrieval of information.

IMPLICIT COGNITION AND DEVELOPMENT

A developmental perspective of knowledge acquisition requires more than identifying dichotomies between implicit and explicit memory or implicit and explicit learning, and it is more than investigating the ages at which children accomplish specific tasks. A developmental perspective involves investigating behavioral and representational changes over time. Karmiloff-Smith (1991) argued for three ways in which knowledge gets into the mind: (a) it is innately specified; (b) it is acquired via interaction with the environment; (c) it is an endogenous process whereby the mind exploits the knowledge that it already has by redescribing its own internal representations, thus creating new representations. The idea of representational change is the focus of Karmiloff-Smith’s model of knowledge acquisition. She is particularly interested in how the cognitive system changes over time, how increasingly abstract representations gradually emerge over time. Her model is pertinent to the study of implicit memory and learning because it addresses the issue of how implicit knowledge already in the mind becomes explicit knowledge available to the mind.
Karmiloff-Smith’s (1986, 1992, 1994) model of representational redescription incorporates a reiterative process whereby children’s representations go through repeated cycles of change. Through the process, existing knowledge is continually reassessed and becomes increasingly flexible and accessible. Her model accounts for how knowledge changes over time; she refers to a level of implicit knowledge and three levels of explicit knowledge, depending on the degree of flexibility and accessibility. Karmiloff-Smith proposed that the representational redescription process occurs spontaneously as part of a person’s internal drive to control one’s environment. The process may be triggered by external events or be self-generated. It is a process of making connections between existing knowledge and new information. Representational redescription is a model of knowledge acquisition that recurs throughout childhood and adulthood.

Karmiloff-Smith (1986, 1992, 1994) proposed that development involves three recurrent phases. During the first phase the child focuses predominantly on information from the external environment; the initial learning is therefore data-driven. During this phase, separate instances or experiences in a particular domain are stored as independent mental representations. New representations neither alter existing representations nor are they brought into relation with them. The child stays in phase 1 until performance matches what he or she experiences in the environment, which Karmiloff-Smith calls behavioral mastery.

Once behavioral mastery is attained, the child no longer focuses on external data, but rather the drive to control his or her internal representations of knowledge. During the second phase, there is a temporary disregard for features of the external environment, which can result in new errors and inflexibilities. There is often a decline in successful performance during this phase. The child’s focus is on making connections between existing representations rather than accumulating more data from the environment. Finally, during the third phase, internal representations and external data are integrated and a balance is achieved.

Karmiloff-Smith emphasized the difference between behavior change and representational change. Although behavioral change often follows a U-shaped curve, representational change can be viewed as a linear progression leading to increasingly explicit and accessible information. Karmiloff-Smith’s model provides a description of the internal representations that sustain the three recurring phases. She argued that there are four levels at which knowledge is represented and redescribed: Implicit (I), Explicit-1 (E-1), Explicit-2 (E-2), and Explicit-3 (E-3). Level-I representations are in the form of procedures for analyzing and responding to the external environment. At this level, perceptual information is encoded sequentially, in procedural form, and new representations are stored independent of previously stored representations. A procedure as a whole is available to the cognitive system, but not its component parts. Thus, information at this level is implicit, but
it often can be accessed quickly and effectively. Behavior generated from Level-I representations is relatively inflexible.

Level E-1 representations are abstractions of conceptual information taken from Level-I representations. Level E-1 representations lose many of the details of the perceptually encoded information in Level-I representations and allow for more flexibility within the cognitive system. For example, Level E-1 representations allow for use of analogy and generalizations to new situations. At Level E-1, representations are no longer stored as independent whole units. Information that was previously embedded in procedural form, is now explicitly defined and available as data to the cognitive system; new connections can be formed and relations between other representations can be made. At this level, information is explicit, but not available to conscious access and verbal report.

Karmiloff-Smith did not make a clear distinction between Level E-2 and Level E-3 representations due to a lack of empirical evidence for Level E-2. However, she hypothesized that Level E-2 representations are available to conscious access without verbal report and Level E-3 representations are available to conscious access and verbal report. Goldin-Meadow and Alibali (1994) supported this hypothesis with their research on gesture. For example, they found that children are often able to express concepts in gesture that cannot be expressed in speech. They proposed that this ability may be evidence of E-2 representations; concepts that can be expressed verbally would be evidence of E-3 representations. The key difference between the two levels is that E-2 representations are nonlinguistically encoded. For example, we often draw diagrams of problems we cannot verbalize. At Level E-3, Karmiloff-Smith suggests that knowledge is redescribed into an abstract, linguistic format that is closely linked to natural language and thus easily accessible to verbal report.

In summary, according to Karmiloff-Smith’s model, knowledge can be represented at multiple levels. Redescription does not replace the original representations; these remain intact and can be used for particular goals at any time. For example, Level-I representations may be called upon when speed and automaticity are required, as in direct retrieval of a known spelling from memory. Level E-3 representations may be called upon when one needs to teach another a particular skill, as in a teacher explaining the ‘‘silent e rule’’ to a Grade 2 child. The representational redescription process is not necessarily hierarchical. Knowledge can come into the system at any level and can be redescribed to another level in any order. For example, we may learn the spellings of new words by mere exposure; hence the word would be coded as Level-I representation. On the other hand, we may be taught explicitly the spelling of a word, or a spelling rule to aid us in spelling a word; hence, the verbal instruction may result in new information being coded at the E-3 level. In the latter case, only when procedural automaticity is reached would it be coded at Level-I. Redescription can occur on-line, that is, in
response to incoming data, or as a product of the internal dynamics of the cognitive system. Karmiloff-Smith’s model of representational redescription addresses some important issues in the acquisition of knowledge. Most important is her model of how existing knowledge changes over time and can be redescribed into new information. The proposal that knowledge can be represented at multiple levels helps avoid the problem of dichotomizing concepts of implicit and explicit knowledge that is evident in the adult literature on implicit/explicit cognition. Karmiloff-Smith highlighted the flexibility that exists within the human mind that allows for continued change beyond behavioral mastery, creativity, and theory building. Representational redescription illustrates the dynamic interaction of information already in the mind and the environment.

Karmiloff-Smith’s distinction between implicit and explicit knowledge is very different from that found in the adult literature. For example, Karmiloff-Smith’s Level-I (i.e., implicit) knowledge is procedural, based on perceptual input from the environment. Once any abstractions are made, this knowledge is referred to as explicit, although it is still unavailable for intentional access and cannot be verbalized. In the adult literature, the distinction between implicit and explicit is based on intention to learn and ability to verbalize or express the knowledge that has been acquired. Reber (1992), for example, presented implicit learning as a process of unintentionally abstracting rules from complex stimuli, resulting in implicit knowledge. Explicit knowledge was knowledge that could be verbalized. Reber’s definition of implicit learning resembles what Karmiloff-Smith refers to as E-1 representations. Karmiloff-Smith’s implicit representations are not abstractions, but are procedures or patterns of responding to the external environment. Perhaps the distinction provides a bridge between the episodic and abstractionist camps in the implicit learning literature.

According to the episodic view of implicit learning in the adult literature, events are stored as separate instances, similar to Karmiloff-Smith’s idea that Level-I representations are stored as whole units. In both views, knowledge at this level is perceptually data-driven. The abstractive view of implicit learning suggests that an abstract representation is derived from the original sensory experience. The abstract representations are generally in the form of structural relations among stimuli that can be transferred across stimulus domains (Reber, 1993). This is similar to Karmiloff-Smith’s notion of E-1 representations. The abstractive view does not specify what happens with the complete perceptual experience, that is, whether it is stored or quickly decays. In Karmiloff-Smith’s model, the existing knowledge base determines whether incoming information is encoded as Level-I (i.e., episodic) or Level E-1 (i.e., abstract) representation. Subsequent redescription occurs with accumulated experience in a particular domain. This, too, is compatible with the suggestions in the adult literature that people are flexible in their approaches
to dealing with complex stimuli and establish different forms of knowledge representation under different conditions (Reber, 1993, 1997; Seger, 1994). Karmiloff-Smith’s multilevel model provides an explanation for this flexibility.

Karmiloff-Smith proposed a developmental model of how knowledge representation changes from implicit to explicit knowledge. Although not exclusively, much of her research is based on children’s language learning. The adult literature, on the other hand, has focused to a large extent on artificial laboratory tests that support the implicit/explicit dichotomy. I do not wish to enter into the debate of what form knowledge is represented. However, there is value in synthesizing general findings from one field of psychology to another. One way of doing this is to explore the ecological validity of findings from laboratory tests in real-world situations.

Although the link between implicit cognition and spelling has not be made in the literature, some researchers have noted that the study of implicit processes is relevant to written language (Berry, 1994; Ellis, 1994). Berry (1994) reviewed several studies that have used implicit versus explicit experimental conditions to investigate second-language learning. Berry pointed out that studies of implicit learning can further the investigation of second-language learning by giving insight into such methodological issues, help shape future theories, and offer suggestions for design of instructional materials and training programs. Although Berry was specifically addressing the relevance of implicit learning studies to second-language learning, her conclusions are equally valid for studying spelling development. A typical research paradigm used to study implicit learning, for example, uses artificial grammars, meaningless strings of letters that are based on a consistent underlying rule-system. A real-world task that is similar in nature to an artificial grammar task is spelling individual words, that is, meaningful strings of letters that are often based on a consistent underlying rule-system. The question is, how is research on implicit learning and memory relevant to spelling development?

**IMPLICIT AND EXPLICIT COGNITION AND SPELLING**

There is no direct one-to-one mapping of the adult implicit memory and learning literature to spelling development. In order to capture a better understanding of the implicit and explicit processes involved, it is necessary to look at spelling from a developmental perspective. As stated earlier, rather than attempting to differentiate implicit/explicit processes, a more important issue is the conditions that facilitate implicit and explicit acquisition of spelling knowledge. Theoretical perspectives from the adult literature on implicit memory and implicit learning do not adequately address the issue of the relation between implicit and explicit processes. On the other hand, Karmiloff-Smith’s model of representational redescription is a framework that does address this issue. Karmiloff-Smith’s model bridges the gap between informa-
tion that is acquired implicitly and explicit knowledge that becomes increasingly flexible and accessible as required in the production of written words.

Many of the early descriptions of spelling development emphasized systematic progressions through a series of stages that characterize children’s knowledge of the spelling system at various points in development (Ehri, 1986, 1992; Frith, 1980; Gentry, 1982; Henderson & Beers, 1980; Nunes, Bryant, & Bindman, 1997; Templeton & Bear, 1992). Viewing spelling development in this way has provided a wealth of information in understanding how children learn the complex task of written language and has offered a foundation for building instructional programs (Henderson, 1990). The early stage descriptions suggested that knowledge of the spelling system progresses from early reliance on phonological information to increasing reliance on orthographic knowledge. More recently, researchers have emphasized the early integration of phonological and orthographic skills (Ehri, 1992, 1997), which highlights the limitations of stage-models of spelling (Lennox & Siegel, 1996; Treiman, 1994). Other spelling researchers have provided evidence to indicate that viewing spelling development in a stage-like fashion does not adequately describe the complexity of children’s knowledge of the orthographic system, even for very young spellers (Goswami, 1992; Lennox & Siegel, 1994; Treiman, Cassar, & Zukowski, 1994; Varnhagen, McCallum, & Burstow, 1997).

Karmiloff-Smith’s multilevel representational model provides a more flexible framework than do discrete stage-models to better understand observations of children’s spellings. Children’s first attempts at spelling often are single-letter productions that have no obvious correspondence to any particular word. Gentry (1982) referred to this as the precommunicative stage of spelling. However, in assessing the criteria that Gentry defined as demonstrative of this precommunicative stage, it is evident that even preschool children have implicit knowledge of writing conventions. For example, these young children may include spaces between their scribbles, demonstrating knowledge of word boundaries; some demonstrate knowledge of directionality by writing from left to right; some include a mixture of upper- and lowercase letters, indicating a sensitivity to the variations in case. In Ferreiro’s (1986) qualitative research on children’s emergent literacy, she reported that 2½-year-old Santiago wrote single letters to represent the names of individual family members. Not only did he believe that these letters “belonged to” the individuals, but also that they could not be shared with others. These spontaneous productions could be interpreted as evidence of Level-I representation. Karmiloff-Smith suggests that these are inflexible, data-driven, procedural representations. It is not uncommon for children’s first-word spellings to include their own names or words that identify common elements in their own world, such as mommy or daddy. Similar to Karmiloff-Smith’s (1990) findings on children’s drawings, her model would predict that chil-
DREN WHO ARE JUST LEARNING TO SPELL THEIR OWN NAMES MAY NOT BE ABLE TO INTERRUPT THE PROCEDURE TO MAKE ADDITIONS OR DELETIONS.

Early in spelling development, children learn to abstract common features from words and map them to orthographic patterns. Four-year-old Jace was asked to write a short dictated paragraph and he produced a series of scribbles with selected letters from his own name. He demonstrated some knowledge of the writing process in that he ‘‘wrote’’ from left to right on the page and the scribbles were periodically spaced as words would be. His production of letters was limited to those included in his own name. According to Gentry’s stage model, Jace would be in the precommunicative stage of spelling. However, such a spelling sample is evidence of E-1 representation because he was beginning to abstract letter information from his own name in an attempt to produce a writing sample.

There is considerable evidence that, even without formal instruction, young children produce spellings that correspond to orthographic regularities and phonetic features of words (Read, 1971, 1975; Treiman, 1993). In Read’s (1971) seminal work on preschool children’s invented spellings, he discussed children’s ‘‘unconscious beliefs’’ about English sounds and structure. Children as young as 3½ were noted to attempt spellings using single letters to represent entire words. Frequently these letter-names sounded like the word the child was attempting to spell (e.g.,  R for are; DA for day). Read presented many examples of preschool children’s invented spellings that were consistent with the predictions implied in Karmiloff-Smith’s model. Treiman (1994) suggested that using a letter-name strategy is much more complex than Read proposed. Treiman argued that children might use a single letter to represent a word (e.g.,  R for car) when they are unable to segment words beyond the syllable. However, as the child becomes more sensitive to phonological segmentation, he or she might spell car as CR, indicating the child’s ability to separate parts of a syllable, and apply the letter name to the rhyme only. Treiman’s interpretation makes a distinction between the child who writes R for car (evidence of Level-I representation) and the one who writes DA for day (evidence of E-1 representation). This development can be understood as representational redescription, the process that increases the flexibility and manipulability of knowledge already stored in the mind.

In a review of how reading and spelling interact, Ehri (1997) reported that beginning spellers stored the spellings of specific words they learned to read in memory rather than alternative phonetically equivalent spellings (Ehri, 1980). Here, we see evidence of Level-I representation that, according to Karmiloff-Smith, is procedural in nature and reflects experiences with words as a whole. However, after as few as three or four practices with words first graders are able to abstract specific letter information from words in memory (Ehri & Saltmarsh, 1995; Reitsma, 1983). The abstraction of specific information is evidence of redescription to Level E-1 representation. One of the limitations of Karmiloff-Smith’s model is that it is unclear how this rede-
scription occurs and why it is that some children have more difficulty than others with representational redescription. The model also does not explain how some children can be good readers and yet be poor spellers. However, because of the specificity of the nature of knowledge representation in Karmiloff-Smith’s model, researchers can begin to address the nature of what is (or is not) learned by able spellers and less able spellers.

Ehri’s (1997) review of how a child develops word-specific knowledge concurs with Karmiloff-Smith’s model of representation redescription. Ehri stated that “knowledge of the [alphabetic] system is the primary stuff used to build word-specific memory.” In Ehri’s theory and research (see Ehri, 1997, for a comprehensive review) knowledge representation is formed by experience with the alphabetic system and consists of graphemes bonded to phonemes (pp. 244–250). In Karmiloff-Smith’s model, this bonding of individual graphemes to phonemes could occur at Level E-1 or E-2 because abstractions are being made from perceptually-encoded information that is stored in Level-I representations. Ehri’s theory of how children match specific letter-sound information could be considered representational redescription in Karmiloff-Smith’s model. Ehri suggested that when children see and pronounce words, their knowledge of the alphabetic system is activated and computes connections between graphemes and phonemes. It is the repetition of the process that bonds the spelling of the word to its pronunciation and meaning (p. 245).

Karmiloff-Smith’s model could explain why some people have difficulty with the bonding process. According to Karmiloff-Smith, behavioral mastery is what triggers representational redescription. Behavioral mastery is attained when performance matches what is experienced in the environment. If poor spellers have not attained behavioral mastery of orthographic or phonemic Level-I representations, then the abstraction of individual graphemes and bonding these to phonemes may not occur. The Lennox and Siegel (1996) analysis of spelling errors supports the hypothesis that poor spellers are more inclined to use perceptually bound Level-I representations than good spellers. These researchers reported that children between the ages of 6 and 16 who were categorized as poor spellers made more errors that were close visual matches to correct spellings, whereas, good spellers made more phonologically based errors. This suggests that poor spellers may be more inclined to rely on visually encoded Level-I representations, whereas good spellers are redescribing this information by making connections between phonemic and graphemic representations. Spelling researchers have suggested that poor spellers fail to encode the details of orthographic structure (Frith, 1980; Holmes & Ng, 1993; Link & Caramazza, 1994). In light of this, it follows that Level-I representations will be incomplete, which, in turn would delay the process of representational redescription.

Karmiloff-Smith (1994) stated that her model of representational redescription was not a stage model, but rather, a model that “invokes recurrent
changes at different times... and repeatedly within each domain’’ (p. 696). This concurs with Sulzby’s (1986) speculation that children have ‘‘less mature’’ writing forms coded simultaneously with ‘‘more mature’’ writing forms and use these different codes for different tasks. For example, Sulzby reported that 5-year-old children may demonstrate the ability to spell individual words in a conventional spelling list format, but when asked to write a story, these same children produced a string of scribbles on a page. Sulzby asserted that ‘‘there is not just one developmental sequence that can be found in children’s use of writing systems’’ (p. 70). Examples of Level-I representations are not limited to preschool children’s attempts at writing. Brown (1988) also suggested that students’ representations of some words in memory may include more than one representation. Brown showed that college students who were exposed to misspellings were more likely to misspell those words on a later spelling test than students who were not exposed to the misspellings, especially for common misspellings. He suggested that these common misspellings were held in memory simultaneously with other spellings for the same word.

Consistent with Sulzby’s and Brown’s work, Karmiloff-Smith’s model proposes that existing representations remain intact and can be used for particular goals at any time. In the Steffler, Varnhagen, Friesen, and Treiman (1998) study on children’s spelling strategies, many fourth- and fifth-grade children reported that they ‘‘just knew’’ how to spell a word. According to Karmiloff-Smith’s model, the Level-I knowledge representations (i.e., before redescription occurred) remain intact for later use. In this regard, automatic retrieval would be evidence of a competent speller drawing on Level-I representations to quickly and accurately retrieve a spelling from memory. Similarly, often when unsure of the correct spelling of a word, spellers will make two or three attempts and then look at the words to see which one ‘‘looks correct.’’ This too could be evidence of Level-I representation. The correct spelling is stored as a unit and when comparing various trial spellings, the speller is accessing the entire unit when using such a visual-checking strategy. The speller may not consciously know what makes the spelling correct; it just looks right. For example, Varnhagen, Gotzmann, Boechler, and Steffler (1999) asked children and adults to choose which word looked most correct from a series of misspelled words, such as *peeches, peechiz, or peachs*. Frequently, participants chose affixed words that included the correct spelling for the root word, but when asked to justify their choice, they often were unable to explain why they chose that particular spelling.

In the Varnhagen et al. (1999) study, some children reported that they chose *peeches* as the correct spelling ‘‘because it had a ch in it.’’ These children seemed unaware that all of the choices included a *ch*. According to Karmiloff-Smith’s model, their justification provided evidence for E-I representation because these children demonstrated that they were abstracting
Karmiloff-Smith’s model emphasizes how people use knowledge that is stored in the system. It is the flexible use of both implicit and explicit knowledge that distinguishes the novice from the competent speller. Researchers who investigate children’s strategy selection in academic domains (e.g., reading, arithmetic, and spelling) have begun to address the issue of children’s metacognitive knowledge while engaged in a particular task. It has been suggested that people may demonstrate implicit knowledge when choosing among various strategies (Nation & Hulme, 1996; Pressley, 1995; Siegler, 1995; Steffler et al., 1999). Siegler (1995) proposed that strategies may be generated from implicit knowledge about procedures that help to meet the demands and goals of a particular task. Similarly, Nation and Hulme (1996) proposed that using an analogy to another known word when spelling a novel word is not necessarily an intentional and conscious strategy. Nation and Hulme suggested that 6- and 7-year-old children demonstrated implicit knowledge of the relationship between sound and spelling when previously presented words facilitated spelling of analogous nonwords the following day.

Neither Siegler (1995) nor Nation and Hulme (1996) defined implicit knowledge. Karmiloff-Smith’s model distinguishes between implicit representation of knowledge and explicit representation of knowledge that is not accessible to the cognitive system, that is, Level-I and Level E-1 representations. Implicit procedural knowledge at Level-I is available only as a whole unit; at this level, cognitive processing is data-driven and pieces of information gleaned from previous experiences are not linked. At level E-1 information is abstracted from existing representations and used to make connections to other representations. Siegler’s and the Nation and Hulme ideas of implicit knowledge may be similar to Karmiloff-Smith’s E-1 representations. It is at this level of representation that analogies can be made, although knowledge about these analogies is not explicitly verbalized. Children using E-1 representation would generalize spelling regularities to new words and be unaware of making the analogy, for example, knowing that cat begins with a c and not ck, but back ends with ck and not c.

In a study that examined strategy selection during spelling, Steffler et al. (1999) found that elementary-school children and adults used a variety of phonetic segmentation strategies for CVCC and CCVC nonwords. Not only did the type of segmentation strategy depend on the word type, but strategy-use positively correlated with correct spelling. Such flexibility in segmenting words when using a phonetic spelling strategy may be a result of Level E-1 representations of linguistic properties of words and/or subjective spelling difficulty. At this level, knowledge about the relations between strategies and outcome are available as data to the cognitive system, but not available
to conscious access and verbal report. In the Steffler et al. study, all children reported a variety of strategies. However, first-grade children, who may not have acquired the knowledge in spelling that facilitates differential segmentation strategies, did not necessarily use effective strategies that were associated with correct spelling. On the other hand, second-, third-, and fourth-grade children and adults did use effective segmentation strategies, indicating E-1 representations that can be manipulated and used to process new information.

Karmiloff-Smith (1992) stated that very little research has been done to differentiate level E-2 and E-3 representations. However, researchers who investigate children’s strategy-use when engaged in a particular task are interested in children’s verbal reports of how they performed the task. Karmiloff-Smith hypothesized that Level E-2 representations are available to conscious access without verbal report and Level E-3 representations are available to conscious access and verbal report. The Steffler et al. (1998) findings concerning strategy use when spelling CVCe words can be interpreted within Karmiloff-Smith’s multilevel representational model. They reported that second- and third-grade children often spelled silent-e words (e.g., ripe) using a phonetic strategy. It is unlikely that a phonetic strategy alone will yield a correct CVCe spelling; the phonetic strategy needs to be accompanied by knowledge of the function of the final e. It is possible that children who reported using a sounding-out spelling strategy and spelled the word correctly were using E-2 representation, having explicit knowledge of the necessity to mark a long vowel with a final e, but not having the explicit knowledge required to verbalize the rule. In another study, Varnhagen and her colleagues (in preparation) found that children in Grade 2 could identify the need to double the final consonant of a one-syllable word before adding a suffix -ing when reading words like taping versus tapping, but did not generalize this concept to spelling production. On the other hand, Grade 3 children eventually learned not only to produce the correct spellings of words like patting, but also correctly expressed the rule (i.e., it is necessary to double the consonant in order to preserve the short vowel sound), thus providing evidence of E-3 representations. When children and adults were asked to state explicitly the strategies used while spelling nonwords, Steffler et al. (1999) reported an age-related trend toward the explicit use of analogy strategy for fourth-graders and adults. Such verbal reports of explicit analogy-use is evidence of level E-3 representations.

One area of spelling acquisition that is intuitively relevant to implicit processing is the acquisition of orthographic regularities. This is often referred to as implicit knowledge of orthographic structure (Assink & Kattenberg, 1993; Henderson & Chard, 1980). Assink and Kattenberg reported a U-shaped trend in the development of knowledge of orthographic structure. These researchers measured orthographic knowledge by asking children in Grades 5–8 to choose between orthographically legal- and illegal-letter
strings in a forced-choice spelling test. Illegal spellings were composed of letter sequences that did not appear in Dutch orthography. For example, in English, _bcat_ for _boat_ is illegal, whereas _boap_ is legal.

Assink and Kattenberg (1993) proposed that knowledge of orthographic structure is primarily implicit and used Karmiloff-Smith’s model to explain their results. Karmiloff-Smith’s model suggests that once a certain level of behavioral mastery is reached, children’s output resembles adult performance, is followed by a temporary decline in performance (which is evidence of representational progression), and later reverts to the adult level. According to Karmiloff-Smith, the temporary decline in performance is a sign of representational progression. In the initial phase of learning orthographic regularities, the child would store isolated entries in memory and behavior would be a result of accessing entire representations. In the next phase, the child is internally driven to search for rules and regularities to develop a coherent system of orthographic representation. During this phase, the child’s focus is on his or her internal representations and there is a temporary disregard for features of the external environment. This disregard for external environmental features can lead to an increase in errors during this phase, which is what Assink and Kattenberg observed in their data. In the final phase, the child endeavors to make links between information that is stored in memory and input from the environment, thus being able to incorporate external stimuli into his or her internal representations of orthographic regularities, which leads to an improvement in performance.

Nunes et al. (1997) reported a similar decline in performance when looking at 6-, 7-, and 8-year-olds’ use of _-ed_ endings. They found an increase and then a decrease in overgeneralizing the _-ed_ ending to nonverbs (e.g., spelling _soft_ as ‘sofed,’ and _next_ as ‘nexcseg’). Seven-year-olds made such errors more frequently than did either 6- or 8-year-olds. These authors suggested this gave evidence for an intermediate stage between using a phonetic strategy and applying grammatical rules. However, such an explanation does not explain why these same 7-year-old children could correctly spell past tense regular verbs such as _killed_ and nonverbs such as _bird_. Karmiloff-Smith’s model emphasizes that behavioral change often follows a U-shaped curve, yet representational change can be viewed as a linear progression. Rather than suggesting that these 7-year-old children are at an intermediate stage of spelling, Karmiloff-Smith’s model suggests that overgeneralization errors indicate that redescription of the _-ed_ orthographic convention is occurring.

The Fischer et al. (1985) research comparing good and poor spellers not only provides further evidence that poor spellers use visual information, but also supports Karmiloff-Smith’s differentiation between behavioral change and representational change. Fisher et al. found that for poor spellers there was no difference in spelling words that required knowledge of surface orthographic features compared to words based on abstract morphophonemic in-
formation, suggesting that poor spellers were using visual information to spell both types of words. However, good spellers performed better on the more abstract morphophonemic words than the words based on surface features. Recall that surface orthographic features are governed by phonetic features (e.g., doubling the *r* in *confer* to make the past tense *conferred*), whereas abstract morphophonemic information is governed by such features as stress placement (e.g., not doubling the *r* in *confer* to make the noun *conference*). Karmiloff-Smith’s model predicts that there will be a decline in performance when representational redescription occurs. During this time, the child will temporarily disregard features of the external environment while he or she focuses on making connections between existing representations. In this regard, the good spellers in the Fisher et al. study may have been experiencing this temporary decline in performance for words that were based on surface orthographic features.

Current explanations of how spellers acquire implicit knowledge of orthographic regularities are similar to explanations used in the adult implicit learning literature. Generally, it is agreed that people acquire implicit knowledge of the underlying rule-structure of complex stimuli by sensitivity to covariations, frequencies, and patterns of the stimuli. Nation and Hulme (1996) suggested that as children are exposed to more words, they also incorporate more knowledge concerning the statistical relationships between sounds and spellings. This knowledge can then be used as a basis for generalization to novel stimuli. However, implicit acquisition alone is not sufficient to account for spelling competence. Children also gain a great deal of knowledge about spelling through explicit instruction, both at home and in the school environment. In the adult literature, a simple dichotomy between implicit and explicit knowledge does not explain the process of developing explicit knowledge from implicit knowledge. However, Karmiloff-Smith’s model could be used as a framework to investigate how children acquire and use both implicit and explicit knowledge when making decisions about how to spell novel words.

Traditionally, it was thought that spelling was a matter of rote memorization. Following Read’s (1971) extensive research on preschoolers’ naturalistic writings, there was a shift from viewing spelling as a rote process to viewing spelling as a creative process. As was popular during the 1970s and 1980s, developmental researchers considered spelling development to occur in stage-like progressions. More recently, spelling researchers have provided considerable evidence of the complexity of children’s knowledge of the spelling system. Spellers use a variety of approaches during spelling and such variability demonstrates considerable flexibility when approaching a spelling task. These findings are consistent with those reported by researchers in other areas of cognitive development. Karmiloff-Smith’s model of representational redescription provides a framework to interpret the acquisition
of and flexible use of complex orthographic structure and regularities of a language.

IMPLICATIONS FOR RESEARCH AND INSTRUCTION

Although Karmiloff-Smith’s model provides a framework to explain the flexibility of children’s spelling, one of its limitations is that it does not explain how representational redescription occurs and why some children do not seem to experience this process as readily as others. For example, children who do not transfer knowledge gained from one experience to another seem to remain at Level-I representation. Karmiloff-Smith’s model needs to be tested empirically to gain a better understanding of how to better assist children in developing explicit knowledge of the spelling system. Clearly, there are many issues that need further investigation in order to develop a cohesive model of implicit and explicit cognition and spelling development. Researchers can benefit from research paradigms used in the adult implicit memory and learning literature in understanding implicit processes used in spelling. Spelling researchers have used priming paradigms to investigate the effects of previous exposure on subsequent spellings. Similar to conclusions in the implicit memory literature, there is some indication that good and poor spellers are equally adept at using implicit memory processes (Dixon & Kaminska, 1997). This line of research needs to be extended to include people with spelling disabilities and the investigation of the circumstances in which spellers use implicit versus explicit memory processes.

There has been considerable debate among educators concerning the “whole language” versus “skills approach” to beginning literacy skills. In a review of both approaches to spelling instruction, Graham (2000) concluded that incidental learning and explicit instruction make separate, but significant contributions to spelling development; natural learning may be superior to formal instruction on some measures of spelling ability, whereas, the reverse is true on other measures. Graham, however, concluded that implicit learning is not as powerful for poor spellers as it is for better spellers. This conclusion concurs with the Nation and McLaughlin (1986) research that investigated natural language learning of monolinguals, bilinguals, and multilinguals on an implicit and explicit learning task. Their rationale was based on the premise that explicit learning involves controlled processing and implicit learning involves automatic processing. The results were that multilinguals performed significantly better on an implicit learning task than either of the other groups and there were no differences in performance among groups on an explicit task. Nation and McLaughlin suggested that the strategies used by “experts” (multilinguals) differed from those used by “novice” learners (monolinguals and bilinguals). They concluded that the multilinguals may have been more successful with the implicit task because they had automated the basic strategies of pattern recognition (e.g., they
tended to use implicit learning strategies in the appropriate environments), whereas the novice learner groups had not. As Karmiloff-Smith’s model implies, one cannot simply equate explicit learning with controlled processing and implicit learning with automatic processing because explicit learning can become automated and, as Nation and McLaughlin’s results suggest, there are degrees of automation in implicit learning. Perhaps there are no differences in ability to learn implicitly at Level-I, but there may be considerable differences in the ability to abstract this knowledge and apply it to new situations, which is required at Level E-1. In spite of the conceptual difficulties of defining the levels of implicit knowledge representation, the Nation and McLaughlin results suggest that the ability to abstract patterns may be associated with flexibility in language learning. If this is the case in spelling, as Graham suggested, then good spellers may be better able to learn and transfer spelling patterns, whereas, poor spellers may need specific instruction to aid in transfer, especially with words that are used less frequently and words that are spelled with uncommon letter patterns. Karmiloff-Smith’s model differentiates between learning that results in inflexible knowledge representation (Level-I) and flexible knowledge that can be transferred to new situations (at the E-1 or E-2 level).

Research on spelling instruction shows conflicting results regarding the ability of poor spellers to abstract regularities from print. For example, Gerber (1986) showed that poor spellers who were experiencing instruction for learning disabilities were able to transfer knowledge of spelling patterns to words that shared the same rhyme. These children practiced words such as *went, sacks*, and *like* and then were able to spell uninstructed words that shared the same letters in the rhyme, such as, *went, backs*, and *bike*. On the other hand, Graham (2000) reviews research that suggests poor spellers were much less successful than good spellers at transferring knowledge of instructed spellings to uninstructed spellings and also are not as likely as good spellers to make gains in their spelling ability from reading (see Graham for a comprehensive review). Karmiloff-Smith’s model provides a framework to investigate various levels of knowledge representation that might explain such differential abilities. In this comprehensive model of knowledge representation, children who do not transfer knowledge of orthographic patterns may be using Level-I representation, whereas, children who can transfer letter patterns to new words may be using Level E-1 or E-2 representations.

Artificial grammar paradigms that are used to study implicit learning could be used to investigate the nature of knowledge that is acquired from mere exposure versus explicit instruction. This methodology could be used as a way of controlling for effects of prior print exposure as well as understanding what types of natural experiences enhance learning. These research paradigms may also be helpful in separating phonological and orthographic infor-
How does spelling ability and existing orthographic knowledge affect implicit acquisition of new information? Perhaps good spellers are better able to abstract rules and structure from language than are poor spellers. If so, what conditions facilitate acquisition of such information?

In addition to investigating retrieval and acquisition issues from an implicit perspective, it is clear that the interrelation of implicit and explicit knowledge is of prime concern. It is this interaction that can most clearly explain the complex nature of spelling development. Karmiloff-Smith’s model provides a framework to interpret both beginning and competent spellers’ knowledge. It may be cognitively economical to use Level-I representations in a typical writing task when speed and accuracy are of prime importance. However, the flexibility of E-2 and E-3 representations are required if a competent speller is instructing children how to spell. The content of these representations will vary according to spelling ability. In Karmiloff-Smith’s model, the criteria for assessing development is related to the flexible use of knowledge, more so than the quantity of information. Further investigation is needed to support the speculations I have made regarding when spellers use the various forms of knowledge representation. Microgenetic studies (see Siegler, 1995) that investigate change as it occurs will give further insight into the developmental nature of knowledge representation. Qualitative and quantitative studies can inform us of the conditions that facilitate change. Obviously, competent spellers have more information about the spelling system than do beginning spellers, but understanding how the information is used can help us develop instructional programs to benefit those who have difficulty mastering the complex task of spelling.

While the brain may be able to learn spelling patterns implicitly and choose adaptive strategies during spelling, students benefit from explicit understanding of the nature and purpose of various types of linguistic information (Fowler & Liberman, 1995; Whitehurst & Lonigan, 1998). Instruction programs can be designed to encourage flexibility by providing opportunities for students to manipulate existing representations and use a variety of strategies, thus gaining the desired flexibility that is characteristic of competent spellers. Whitehurst and Lonigan (1998) highlighted the importance of developmentally appropriate interventions and recommended the use of computer-assisted instruction to address the unique needs of individual children. As Whitehurst and Lonigan suggested for phonemic awareness instruction, computer-assisted instruction could be implemented toward the acquisition of orthographic skills. Computer-assisted instruction would encourage learning through active exploration and interaction with the advantage of immediate feedback. Such a nonjudgmental environment would allow children to investigate possible relationships between graphemes and phonemes and various intraword letter combinations. Computer-assisted instruction designed to enhance orthographic skills would need to be evaluated for specific features that
contribute to any effects. Karmiloff-Smith’s multilevel model of knowledge representation provides a framework for investigating the types of experiences that augment learning.

In this review paper I attempted to integrate research in memory and learning with spelling development. I highlighted the key theoretical issues in the adult literature and proposed that researchers seriously consider the role of implicit knowledge in spelling development. Using ‘‘rules’’ during spelling may involve implicit knowledge of sound-spelling correspondences, orthographic regularities, frequencies, and statistical probabilities used during automatic retrieval, as well as explicit phonological knowledge and knowledge of orthographic conventions. Some of what we learn during spelling development is implicit and seems to be acquired naturally. In stating this, I do not intend to underemphasize the importance of instruction in developing explicit awareness and spelling competence. Both novice and competent spellers use implicit and explicit processes. The strength of Karmiloff-Smith’s model is the emphasis on the interrelation of these processes and increasing flexibility and manipulability as spelling competence develops. We need further research to understand how spelling ability affects the use of implicit and explicit processes during spelling. Although I have provided post hoc evidence in support of Karmiloff-Smith’s model of representational re-description, the ideas presented are necessarily subject to empirical scrutiny. However, her model does provide promise for integrating the diverse streams of research in the area of spelling development.

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