CHAPTER

8

Working Memory in the Classroom

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There have been many claims by cognitive psychologists that working memory (WM) plays a role in learning during childhood, supported by studies demonstrating close links between WM skills and measures of learning and academic achievement. An important shortcoming of this approach is that it does not illuminate how and why WM is needed in the everyday classroom activities that form the basis for learning. This is unfortunate because this is the information needed by teachers and other education professionals wishing to improve the learning outcomes for children with WM problems.

The aim of this chapter is to begin to redress this situation by investigating some of the ways in which WM may contribute to the process of acquiring knowledge and complex skills in school. Following a review of relevant research evidence, findings are reported from a study in which children with poor WM skills were observed in the course of their normal classroom activities. Activities that demand WM were found to be common in all classes observed and were particularly frequent in literacy and mathematics lessons. Children with poor WM skills experienced particular problems in carrying out complex tasks that required both memory storage and effortful processing such as writing and counting and in remembering instructions. They had difficulties in keeping track of their place in complex task structures, particularly when writing. Poor episodic memory for the relatively recent past was also observed in this group.

The possible psychological mechanisms linking WM failures to impairments in the acquisition of knowledge and complex skills are considered in

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Working Memory and Education

this chapter. We also discuss the implications of these findings for classroom practice, and in particular for minimizing the learning difficulties that result from WM failures.

WORKING MEMORY AND EDUCATIONAL ACHIEVEMENT: A REVIEW

Over the past two decades cognitive psychologists have intensively investigated the possible causes of low educational achievement. A consistent finding from a large number of studies is a close relationship between children's performance on indicators of scholastic attainments and their WM skills. Young people with low scores on standardized assessments of reading and mathematics usually score poorly on complex memory span tasks that involve both the processing and temporary storage of verbal reading mate-
1 rial (e.g., Bull & Scerif, 2000; de Jong, 1998; Gathercole & Pickering, 2000a; McLean & Hitch, 1999; Passolunghi & Siegel, 2001; Swanson, 1994). A typical example of such a task is listening span, in which the participant makes a judgment about the meaning of each of a series of spoken sentences and then attempts to recall in sequence the final word of each sentence.

Complex memory span tasks have been suggested to depend on WM. One popular view of WM is that it is a limited capacity system that operates as a kind of mental workspace in which material can be both processed and maintained (Case, Kurland, & Goldberg, 1981; Daneman & Carpenter, 1980; Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992). According to this view, activities that place heavy burdens on either processing or storage are likely to place excessive demands on limited resources and therefore will overload the system and result in task failure.

An alternative account is associated with the more detailed WM model of Baddeley and Hitch (1974), elaborated by Baddeley (1986, 2000). This model consists of three components. The central executive is an attentional system responsible for a range of regulatory functions including attention, the control of action, and problem solving. This component is supplemented by two limited-capacity slave systems. The phonological loop is a slave system specialized for the temporary storage of material that can be represented in a sound-based form. The visuo-spatial sketchpad stores and maintains visual or spatial information for brief periods. It has been suggested that, whereas the processing component of verbally based complex span tasks such as listening span is supported by the central executive, the storage needs are met by the phonological loop (Baddeley & Logie, 1999; Duff & Logie, 2001).

The learning problems associated with poor WM skills are substantial. In England, children with low scores on WM assessments have been found to perform poorly on national curriculum assessments at the ages of 7, 11, and

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14 years (Gathercole & Pickering, 2000b; Gathercole, Pickering, Knight, & Stegmann, 2003; Jarvis & Gathercole, 2003). In some cases, the learning difficulties of children with below-average WM function are sufficiently severe to warrant special educational support in school (Alloway, Gathercole, Adams, & Willis, in press; Gathercole, 2002; Gathercole & Pickering, 2001; Pickering & Gathercole, 2004). More generally, many studies have shown that weak WM function is a characteristic of children with learning disabilities in literacy or numeracy or in both areas (Bull & Scerif, 2001; De Jong, 1998; Mayringer & Wimmer, 2000; Siegel & Ryan, 1989; Swanson, 1994; Swanson, Ashbaker, & Sachse-Lee, 1996). 2

How Does Working Memory Constrain Learning? 3

What, then, is the underlying basis for the association between WM and learning? Two main types of explanations have been advanced and are represented in Figure 8.1. One possibility (Model 1) is that WM limitations result from difficulties in a particular processing domain. By this account, children with poor skills in processing spoken language may obtain low listening span scores because they are unable to meet the processing demands of listening to a sentence and making a semantic decision, and this leads to task failure. They would also be expected to struggle to learn to read as a consequence of their weak language processing skills. In this situation, neither the low listening span scores nor poor levels of academic achievement are a result of poor WM capacity *per se*; instead, they are both consequences of a primary language processing problem.

The evidence in support of this model is not compelling. Many studies have demonstrated that the relationships between WM measures and high-level cognitive skills such as reading and mathematics are not explicable simply in terms of the processing element of specific WM tasks (e.g., see Engle, Tuholski, Laughlin, & Conway, 1999, for a review). It appears that it is the general capacity of WM that is crucial, and not skill within a particular processing domain. 4

The alternative view (Model 2 in Figure 8.1) is that WM capacity directly constrains the ability to learn complex skills and to acquire knowledge. The detailed processes by which WM contributes to the acquisition of complex skills and knowledge during the school years are not, however, well understood. Statistical associations between WM assessments and outcome measures of learning (e.g., reading, mathematics) do not cast light on these processes because these measures tap the endpoints of scholastic attainment and thus provide no information regarding the nature of failed individual learning episodes that led to poor attainment levels.

The contribution of WM to mental arithmetic in particular has been investigated more directly using experimental methods. Consistent with the view that WM is used to support storage and processing in the course of mental arithmetic, mathematic calculations have been found to be more accurate

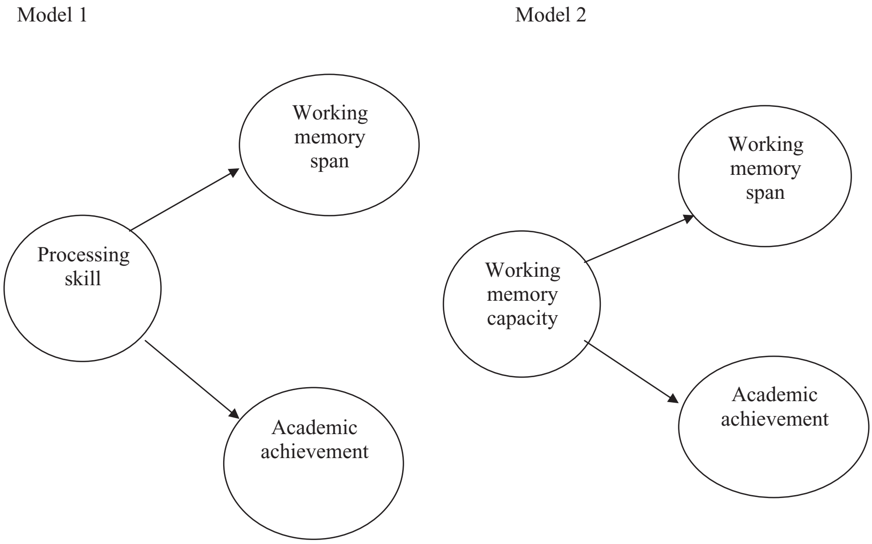

FIGURE 8.1
Alternative models of the relationship between working memory and achievement.

when the numbers in the problem are visible throughout calculation, hence alleviating the WM burden (Adams & Hitch, 1997). Other studies have used dual-task procedures to impair selectively the operation of specific components of WM during arithmetic calculations. This research has yielded strong evidence for central executive involvement in mental addition (De Rammelaere, Stuyven, & Vandierendonck, 2001; Furst & Hitch, 2000; Logie, Gilhooly, & Wynn, 1994) and for the contribution of the phonological loop to the storage of problem information (Furst & Hitch, 2000; Logie et al., 1994). The loop may also play a more specific role in supporting multiplication (Lee & Kang, 2002).

Although these studies provide valuable insights into how mental arithmetic may be limited by poor WM function, it should be noted that because participants were adults in most cases, the results reflect the cognitive processes involved in skilled mathematic functioning rather than the acquisition of mathematic skills. There have been no investigations, to our knowledge, either of the WM loads of real-life learning activities, or of the specific difficulties experienced by children with poor WM function in the classroom. This limits the practical applications of the substantial evidence that WM plays a crucial role in supporting the acquisition of knowledge and complex skills during the school years. To provide effective remedial support for children with poor WM skills, it is necessary to anticipate, alleviate, and compensate for these problems in school. These questions can only start to be answered effectively if the role of WM in the classroom is known.

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OBSERVING WORKING MEMORY IN THE CLASSROOM

Our study investigated WM and learning directly, by observing and analyzing the WM constraints of routine classroom activities. The aim of the study was to bridge the gap between educational practice and the empirical evidence that WM is a conduit to academic learning during the school years, complementing the outcome-based studies that form the scientific foundations for the study. Our specific objectives were to provide a detailed analysis of the learning situations in which WM demands are sufficient to impair progress toward learning goals in some children and to begin identifying means by which the learning difficulties that may arise from poor WM function can be alleviated.

The WM demands of regular activities across the range of curricular and noncurricular activities in the course of a normal school week were observed in classes of 5- and 6-year old children in four state primary schools in an urban area of northeast England. The observations focused on 3 boys who had been identified 1 year earlier as having poor WM test scores shortly after commencing full-time schooling, as part of a large-scale screening study of memory and more general cognitive function of children in reception classes (Alloway, Gathercole, Willis, & Adams, 2004). In what follows, the 3 children are referred to using the pseudonyms of David, Philip, and Joshua.

The children's scores on standardized ability tests are summarized in Table 8.1. Testing occasion 1 was the original screening study; at this time, the children's ages ranged between 4 years 10 months and 5 years 2 months. Testing occasion 2 took place between 9 and 12 months later, when the children were in Year 1 classes. These children were selected on the

TABLE 8.1
Standardized Scores on the Cognitive and Behavioral Assessments, for Each Child

Area of Assessment	Test	Testing Occasion	David	Philip	Joshua
Working memory/ central executive	Backwards digit recall	1	56	71	56
	Counting recall	1	67	70	70
	Listening recall	2	73	73	55
Phonological loop	Nonword recall	1	98	78	86
		2	89	85	89
	Word recall	1	92	108	81
		2	101	101	105
	Digit recall	1	97	83	86
Nonverbal ability*	Object assembly	1	7	10	8
	Block design	1	11	5	8
		2	11	5	9

*Scaled scores (mean = 10, SD = 3).

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basis of low scores on the first occasion (=>2 *SD* below the mean) on 2 complex span measures (Backward Digit Recall and Counting Span) from the Working Memory Test Battery for Children (WMTB-C; Pickering & Gathercole, 2001). Their average standardized scores on 3 phonological loop measures (the Children's Test of Nonword Repetition, Gathercole & Baddeley, 1996; Word List Recall and Digit Recall from the WMTB-C) fell within 1 *SD* of the mean. The mean scaled scores on 2 performance subtests (block design and object assembly) of the Wechsler Preschool and Primary Scale of Intelligence—Revised (WPPSI—R; Wechsler, 1990) fell within a standard deviation of the population mean for each child.

Each child was observed in the course of normal classroom activities for 3 or 4 days. At the end of this period, the children were reassessed on 2 phonological loop tests and 1 complex span test from the Working Memory Test Battery for Children. They were also given the block design test of the WPPSI—R. Test scores on this second testing occasion are shown in Table 8.1. In addition, the class teachers rated the children's behavior using the Conners' Rating Scale for Teachers (Conners, 1997), a measure devised to detect attentional problems. Responses are scored on 4 scales—oppositional, cognitive problems/inattention, hyperactivity, and the Conners' ADHD (attention deficit/hyperactivity disorder) index.

The aim of the observations was to identify the learning situations in which the WM demands have detectable consequences on a child's ability to complete a task satisfactorily. The observer was seated in a position allowing a clear view of the target child but in a location that did not disrupt ongoing individual and group activities and that did not alert the child to the ongoing observation. Observations were recorded in note form at the time of observation. The following operational definition of WM demands was adopted to guide the observations:

> The requirement of temporary mental storage, or temporary storage combined with ongoing processing, that is sufficiently demanding to lead, on occasion, to failures to complete target activities.

Although the primary focus of the observer was the target child, WM loads in other classroom activities that did not include the target child were also observed and recorded where possible. Note was also taken of methods used spontaneously by the child, teacher, or any other person to alleviate the WM demands of specific activities, with the aim of identifying good practice where possible.

Profiles

Characteristics of the behavior of each child and his or her performance on cognitive assessments are provided in the following. The behavioral profiles of the children are based both on teacher reports and the observer's own impressions of the academic and social functioning of each child.

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David

David's scores on the complex memory span tests fell considerably below the population mean at the times of both the original assessments of Backwards Digit Recall and Counting Recall at 4 years of age and the Listening Recall test at 5 years. Performance on phonological loop measures was normal for age at both points in time, as was David's performance on the nonverbal ability tests. Scores on the Conners' Teaching Rating Scale (Conners, 1997) indicated significant attentional difficulties on one scale, Cognitive Problems/Inattention. According to the test material, high scorers on this scale may be inattentive, have more academic difficulties than most individuals of their age, have problems organizing their work, have difficulty completing tasks or schoolwork, and appear to have trouble concentrating on tasks that require sustained mental effort.

David was a reserved, well-behaved child who was observed to be reasonably well-liked by his classmates. He rarely contributed to class discussions unless asked directly and was generally reticent about offering information. At the time of observation he was placed in the lowest ability group in the class for numeracy. In literacy he had just been moved up from the lowest ability group to the next group up to minimize contact with another child who was considered to be a bad influence.

Joshua

Joshua performed very poorly on the complex memory span measures on both occasions, but he scored within the normal range on the phonological loop tests. His performance on the nonverbal ability tests was also normal for age at both times of testing. Joshua's scores on the Conners' Rating Scale for Teachers identified no significant behavioral problems.

Joshua was observed to be a quiet child who was obedient in the classroom and was well liked by his peers. He had a characteristic style of responding slowly in all tasks. Joshua often failed to follow general class instructions and required frequent reminders. His teacher described him as being in a world of his own. During observation he rarely contributed to class discussions and, at the time of observation, was in the lowest ability groups in both numeracy and literacy. Joshua frequently showed overt signs of frustration, including pulling faces and banging his head with his hands, during activities at which he was struggling.

Philip

Philip obtained very low scores on all three assessments of complex memory span, with phonological memory scores falling within the average range. Philip's performance on the object assembly test from the WPPSI was normal for his age, although he did perform at low levels on the block design test on both testing occasions.

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Philip had a very pleasant and cheery personality. He was well behaved and popular in his class. His performance was poor in the areas of both numeracy and literacy and, at the time of observation, was in the lowest ability group in literacy. He frequently became frustrated by the difficulties that he experienced, particularly in writing. Philip did not often participate in class discussions, and on several occasions he was observed to be unable to respond even after he had raised his hand in response to a question by the teacher. Philip showed awareness of his memory problems, making comments such as, "I forget everything, me." No behavioral problems were identified for Philip on the Conners' Rating Scale for Teachers.

Observed Memory Failures

David, Joshua, and Philip struggled in many of their classroom activities, reflecting their generally low levels of academic ability. Task failures that appeared to be the result in part, at least, of failure to meet the WM demands of the situation were observed in all three cases and were particularly common in the daily numeracy and literacy sessions. These failures were many times more common than those observed in two further children selected on the basis of very poor phonological short-term memory but normal complex memory span performance. The main categories of memory-related failure observed in David, Joshua, and Philip are described in the following.

Forgetting Instructions

The most commonly observed memory-related failure in all three children was an inability to follow instructions from the teacher. This failure appeared to be the result of forgetting the content of the instruction, particularly when it was fairly lengthy and did not represent a routine classroom activity. Some examples are provided in the following.

> "*Put your sheets on the green table, put your arrow cards in the packet, put your pencil away and come and sit on the carpet.*"

David failed to put his sheet on the green table. The teacher asked David if he could remember where he was supposed to put it; he could not and needed reminding.

> "*Put your arrow cards in their packets and come and sit in a circle on the floor.*"

David put the cards away and then sat at his desk with arms folded.

> "*Can you collect the books in from the yellow and green table, please, and put them on the shelf?*"

Having collected the books, Joshua had to ask where to put them.

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Joshua was handed his computer login cards and told to go and work on computer number 13. He failed to do this because he had forgotten which computer he had been told to use.

Philip was asked to go back and put an "n" in the word *bean*. He went back and asked the classroom assistant what he had been asked to do.

In each of these instances, the child has to process linguistic information that includes some fairly arbitrary content. Such material has been found to place substantial demands on short-term memory, which is needed to support off-line linguistic analysis (Baddeley & Wilson, 1988). Poor short-term memory capacity would be expected to lead to failures to process such instructions adequately and may explain the difficulties experienced by each of these children in grasping the structure of many classroom activities.

Failing to Cope with Simultaneous Processing and Storage Demands

David, Joshua, and Philip all frequently struggled in structured activities whose successful completion involved engaging in a relatively demanding processing activity at the same time as storage of information. Many of these activities involved counting. Although all three children were capable of counting accurately in the context of a simple task, many classroom activities combined counting with other cognitive processes. One frequent activity in literacy sessions involved counting the numbers of words in a sentence, often prior to writing the sentence down. Joshua was unable to recall the sentence, isolate each word, and count it without assistance from the teacher. A group activity in Philip's class was to count the number of sentences in a text. Philip was unable to keep track of the tally number while reading aloud the text. In both cases, the task failure appeared to result from combining the memory demands of counting (keeping track of the tally number) in the context of a concurrent and fairly demanding processing activity.

There was frequent use in each classroom of number aids, designed to facilitate children's grasp and mastery of counting and basic arithmetic. Examples included number lines, number fans, and "Unifix" blocks. In each case, the device provides a means of representing number physically. The children in the low WM group struggled to take full advantage of the support potentially provided by these number aids. Number lines are designed to facilitate counting by allowing the child to jump one step at a time from a starting number. Joshua was encouraged to use a number line when counting up the number of ducks shown on two cards, but he struggled to coordinate the act of jumping along the line with counting up to the second number. He abandoned the attempt, solving the sum instead by counting up the total number of ducks on the two cards. Similarly, Philip was observed to choose not to use the number line when available; instead he counted on his fingers.

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In both cases, the unfamiliar activity of counting along the points of the number line to a stored target number appeared to impose a greater WM load than simple counting of the physical events.

Further failures were observed in tasks that involved the detection of target items in spoken or written text. These tasks imposed significant processing demands (analysis and comprehension of spoken language, or text reading) in conjunction with the storage of multiple items. For example, the children in Joshua's class were asked to identify the rhyming words in a text read aloud by the teacher. They had to wait until all four lines had been read before telling the teacher the two words that rhymed: *tie* and *fly*. This task involves matching the sound structures of a pair of words and storing them. Joshua was unable to do this. A related activity in David's class involved the teacher writing number sequences on the white board with some numbers missing. She counted the numbers aloud and asked the class what numbers she had left out. In each case, there was more than one number missing (e.g., 0, 1, 2, 4, 5, 7, 8). Here, the child had to use his or her number knowledge to identify each missing number and store them. David was unable to tell the teacher which numbers she had missed out on any of the occasions.

All of the tasks discussed here share the common feature of imposing significant processing demands on the child at the same time as creating a storage load. In themselves, the storage loads do not appear to be particularly excessive. In the case of counting-based activities, the child simply has to retain the tally number and sometimes the target number to which he must count, and, in the examples of the detection tasks supplied listed previously, the child had only to store two items in each case. In isolation, it seems likely that the child would be able to meet these storage requirements without difficulty. The task failures appear to arise from the combining storage with the significant processing demands of the task. These task features are, of course, also shared by the complex memory span tasks on which David, Joshua, and Philip scored so poorly and have been strongly associated with general WM capacity.

Losing Track in Complex Tasks

David, Joshua, and Philip experienced marked difficulties in writing a sentence either generated by the child himself or provided by the teacher. The task structure of writing a sentence accurately consists of a hierarchy involving three levels—letters, words, and the sentence. If the sentence is internally generated by the child or spoken by the teacher, its surface form needs to be maintained to guide the writing of the words and their individual letters, and the child has to keep track of the position in the sentence while writing. If the task involves copying a sentence, the burden of sentence representation in WM is reduced, but the child still needs to keep track of his position while writing.

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Two types of failure were observed in writing. The first type of error involved the child forgetting either some or all of the sentence content. This was relatively easy to identify because it was common practice for teachers to check with children in lower-ability groups if they were able to repeat the sentence before beginning to write it. David, Joshua, and Philip all demonstrated on occasion that they were unable to do this. The second type of error involved the child losing track of his position in the sentence. This resulted in omission of words, repetition of words (when the child forgot that the word had already been written), intrusion of words that were not in the target sentence, and (frequently) abandonment of the task.

David provided an example of both types of writing failure when he was working with his teacher and the rest of the low-ability group. The teacher decided that the children should write "He had 36 barrels of gunpowder." The sentence was repeated until the children appeared to remember it. David successfully wrote "he" and "had" and then could not remember what to write next. The teacher asked him to read what he had already written and then to say what word came next, but he could not. The teacher reminded him of the sentence. David then got stuck after writing several letters of the word "gunpowder," attempted and failed to get the teacher's attention to help him, and then forgot that the word needed completing.

A further example of a place-keeping error was provided by Philip. The teacher wrote on the board "*Monday 11th November*" and underneath, "*The Market*," which was the title of the piece of work. Philip lost his place in the laborious attempt to copy the words down letter-by-letter, writing "*moNemarket*." It appeared that he had begun to write the date, forgot what he was doing, and began writing the title instead.

One of the reasons that place-keeping failures were particularly common in the WM group even when copying from a board or card was that the children wrote the letters on a one-by-one basis rather than in a larger group or word. This strategy presumably reflected the children's poor knowledge of spelling patterns, reducing the opportunity for chunking letter groups. As a consequence, the child had to remember not only his place in the word sequence of the sentence, but the letter sequence of each word. Effectively, this means that the children with low WM skills were working with a more complex task structure (a hierarchy involving three levels of unit—letter, word, and sentence) than more able children for whom task hierarchies were reduced to two levels (word and sentence), imposing a commensurately greater place-keeping load.

Episodic Forgetting

The main focus of the observations was on task failures that may have been the result of excessive WM loads for this group of children. Longer-term memory failures were, however, also frequently observed in this group, with all three children failing on several occasions to remember information that they had encountered in an earlier activity in the day. Memory for specific events in the relatively recent past is known as "episodic memory" (Tulving, 1983) and traditionally represents a functionally distinct system from WM or short-term memory (Baddeley & Warrington, 1970).

The following examples illustrate the poor episodic remembering of the three children. David's teacher discussed bonfire night and read the story of Guy Fawkes to the class. When David was asked, "*What might you see in the sky tomorrow night?*" he failed to answer *fireworks*. He was also unable to say what Guy Fawkes planned to do, even after writing the sentence in answer to the question. Similarly, in a class activity involving the teacher and class together reading from a big book, Joshua was unable to answer any questions asked about the text.

A number of episodic memory failures were also observed for Philip. For example, he failed to remember the three vegetables that a character had bought in a book read by the class together. As reported earlier, Philip showed considerable awareness of his poor memory abilities. When the teacher told them to learn their spellings that night ready for a test the next day, Philip responded by slapping himself on the forehead and saying, "*If I remember!*"

These observations raise the interesting possibility that episodic memory is based in part at least on records from the more temporary storage systems corresponding to WM. Baddeley (2000) has made a similar suggestion based on the identification of a new component of WM, the episodic buffer. The function of the buffer is to integrate multiple sources of memory information, effectively binding representations from different modalities and representational domains (e.g., other components of WM as well as more durable memory systems) in a way that may generate the experience of consciousness. Furthermore, Baddeley suggested that the episodic buffer is linked to episodic memory. The current observations of frequent episodic forgetting in children with poor WM function fit well with this proposal.

Other Observations

Despite their contrasting personalities, there were a number of interesting commonalities in the classroom behavior of David, Philip, and Joshua. First, all three children were reserved in group and class discussions, rarely volunteering information or raising their hand in answer to questions. This was notable particularly in the case of Philip, who was outgoing and humorous by nature in more informal social interactions. Because teachers often asked the children questions about recent activities as part of these discussions, it is possible that the poor episodic remembering of these children (possibly resulting from a primary problem in WM) prevented them from participating in these exercises.

A further similarity between all three children was their preference for simplifying tasks where possible. An example of this was provided earlier

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for Philip, who would not use a number line to add the two numbers corresponding to the number of ducks on two cards together. Instead, he counted the ducks individually. It was argued that in doing so Philip was avoiding the additional processing load involved in jumping along a number line a specific number of times (which had to be stored). His preference was for simple counting of physical objects—a more highly practiced activity that imposes reduced processing and storage loads.

Joshua also demonstrated a tendency to simplify tasks in a way that was likely to reduce memory loads. Children in his class were taught a five-stage process for learning spellings, known as "look, say, cover, write, check." Joshua avoided the memory test element of this procedure of covering the spelling and chose instead simply to copy the word down a second time with the target word in full view.

It is notable that in both of the examples, the learning benefits associated with the specified learning activity are likely to be reduced by the children's simplification of the tasks. Joshua's choice not to cover the original spelling when copying the word a second time is likely to have prevented him from valuable retrieval practice and the subsequent opportunity for self-correction in the case of an error. In the case of Philip, his dependence on simple counting rather than use of an external memory aid would potentially have increased the WM load of the task. It is possible that the tendency to simplify complex tasks reflects the children's avoidance of situations in which they lose their place in task hierarchies. Paradoxically, the consequence for the child is likely to be increased, rather than reduced, rates of learning failure.

LEARNING IS BASED ON SUCCESS

In the previous sections we described some of the learning failures observed in common classroom activities that can be attributable failures of WM resulting from excessive memory demands of the tasks or from the very poor WM capacities of some children. Could these failures underlie the difficulties experienced by some children in making normal educational progress through the school years? Certainly, the poor performance on WM assessments of David, Philip, and Joshua predated their failures to progress normally in the crucial scholastic domains of literacy and numeracy.

Some insights into why classroom failures may compromise learning in this way is provided by research comparing learning under conditions where errors are prevented ("errorless learning") with learning in situations in which the participant learns by trial and error ("errorful learning"). Studies of individuals with memory deficits resulting from acquired brain damage have consistently shown a substantial benefit to errorless learning (e.g., Baddeley & Wilson, 1994; Clare, Wilson, Carter, Roth, & Hodges, 2000; Parkin, Hunkin, & Squires, 1998). One explanation for this finding is that

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responses in specific situations are based on long-term memories from previous related episodes. The probability of a correct response being generated in a particular situation is, therefore, greater if the participant has consistently made correct responses in the past than if prior responses were inconsistent.

This analysis may provide a simple explanation for why children with poor WM abilities experience difficulties in learning during the school years. The frequent WM-related errors that these children were observed to make in the course of complex learning activities may have impeded their chances of acquiring crucial skills in the domains of literacy and numeracy because they prevented the successful completion of relevant tasks. Task errors and failures to complete target activities constitute exactly the type of errorful learning situations previously shown to compromise learning achievements. If a child has poor WM, it is therefore extremely important to minimize chances of task failure resulting from WM overload.

IMPLICATIONS FOR CLASSROOM PRACTICE

To manage WM loads effectively in the course of classroom activities, it is important to be aware of the memory capacities for that age group. It is not in the interests of the smooth running of the classroom that children engage in activities in which many of them will fail because of excessive memory demands. This situation will result in frequent requests by children for reminders that will disrupt the lesson and also in some children abandoning activities because they cannot remember what is required of them. These situations represent lost learning opportunities.

The data plotted in Figure 8.2 are taken from the standardization data for the Working Memory Test Battery for Children (Pickering & Gathercole, 2001; see also Gathercole, Pickering, Ambridge, & Wearing, 2004). This battery provides multiple assessments of each of the main components of the Baddeley & Hitch (1974) WM model and is suitable for use with children aged 4–15 years of age (see Chapter 9 for a detailed description of this
5 test). Phonological loop assessments include Digit Recall, Word List Recall, Nonword List Recall, and Word List Matching. Visuo-spatial tests are Block Recall, Visual Patterns Test (Della Sala, Gray, Baddeley, & Wilson, 1997), and Mazes Memory. Central executive measures are Listening Recall, Counting Recall, and Backward Digit Recall. The data points were obtained by calculating *z*-scores for each subtest across the standardization sample as a whole and then averaging the scores across different subtests tapping each component of WM to produce composite scores.

The figure shows that WM capacity develops steadily across the primary and secondary school years. Children's abilities to cope with the memory demands of particular activities will therefore depend very much on their age. The likelihood of WM-related failures is greatest in the early school

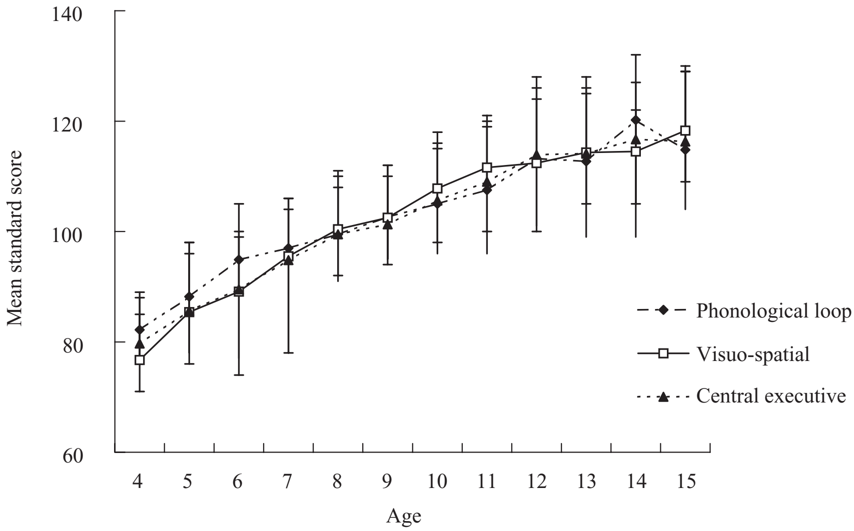

FIGURE 8.2

Mean standard scores as a function of aspect of working memory, with 10th and 90th centiles.

years, diminishing gradually in older age groups. As a rule, most children's scores on WM assessments are close to those of the average adult by 14 years of age. At the age of 6 years, they are approximately half of this on measures associated with the central executive and visuo-spatial sketchpad and about three-fourths of this on measures of the phonological loop. This marked reduction in WM capacity in younger children should be borne in mind when planning their learning activities.

It is also important to recognize that some children in a class will have much poorer WM than others. There is a substantial degree of individual variability in WM abilities, as demonstrated by the difference between 10th and 90th centile plots in Figure 8.2. A typical class of 9-year-old children is therefore likely to include individuals whose WM capacities vary from that of the average 7–12 year old.

We now turn to the issue of when one might consider the possibility of a WM deficit in a child who is failing to progress well in class. The case studies reported here give some indication of the behavioral and cognitive profiles that are associated with WM deficits. The children we observed did not usually exhibit overt behavioral problems, and they showed reasonable social adjustment. They were, however, reserved in school and unwilling to participate in class discussions. In all aspects of the classroom, they often had difficulties following instructions that involved unfamiliar or arbitrary sequences of actions. Their learning difficulties were manifest in frequent failures to complete activities involving significant cognitive processing

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loads in the course of more complex tasks involving memory storage. Examples include attempting to spell an unfamiliar word while writing a sentence from memory and carrying out a numeric calculation abstracted from a question expressed in everyday language. In these situations, children with poor WM function are likely to lose their place in the complex task structure, resulting in frequent repetitions, place-skipping, or task abandonment.

WM deficits are not easy to detect on the basis of informal contact alone and can easily be misclassified either as attentional problems or more pervasive cognitive impairments. Comments made to us by teachers about children with poor WM abilities include: *"He doesn't seem to listen to what I say"* and "*It's in one ear and out the other*."

A notable finding of our observational study was that children seem to be capable of considerable insight into their memory failures. Philip, a child with very poor WM function, commented to the classroom assistant, "*I forget everything, me!*" On other occasions, we observed failures that were likely the result of high WM demands in children with normal WM skills for their age. One child was given a long series of task instructions by her teacher and failed to complete the activity. When asked why, she commented, *"Mrs. McGregor told me a lot and I forgot*." In another class-based activity in which children had to clap one more time than the preceding child in a circle, many children failed to clap the correct number of times. Two children spontaneously exclaimed, *"I forgot the number!"* One valuable strategy for identifying children with WM problems may therefore be, quite simply, to ask them why they have failed in a particular activity: Insight appears to be reliable.

In considering the possibility that a child has a WM deficit, it is worth bearing in mind that there are a number of crucial differences in the behavioral and cognitive profiles associated with poor WM, attentional problems, and general cognitive deficits. First, children with low WM usually score in the normal range on systematic assessments for attentional deficits or show problems only related to inattention. The nature of the link between ADHD
6 and WM is not yet completely clear (as indicated in Chapter 6 of this book). Children with low WM do not seem to have the problems of social integration with peers that are characteristic of ADHD. Second, individuals with general cognitive impairments are distinguished by across-the-board deficits in cognitive tests that include both WM and nonverbal ability measures, and they show comprehension problems. In contrast, children with poor WM perform at normal levels on nonverbal assessments and are less likely to have problems with comprehension.

The best way to identify WM deficits is to assess them directly using tests standardized for use with children (e.g., the Working Memory Test Battery for Children). When assessing WM capacity, it is important to use a number of tasks with varying processing demands. This is necessary to determine
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ticular domain or a more general decrement in WM capacity. For example, some children have specific difficulties with numbers. These individuals inevitably will score very poorly on WM tasks that involve counting as the processing activity (as in the case of Counting Recall, for example) because the level of task difficulty will be higher for them than for other children. In these cases, a low counting span score may reflect a specific counting problem rather than a general WM deficit. To distinguish between these two possibilities, it is necessary to test the child on other WM tasks that do not tax the same processing activity. Listening Recall, in which the processing activity involves making a decision about a spoken sentence, would be a good alternative measure. A child with poor WM capacity would be expected to score poorly on this task, too, whereas a child with only a counting problem would not.

Minimizing Working Memory Failures in Learning Situations

Once it has been detected that a child has poor WM abilities, the next step is to identify the learning activities that will place heavy memory demands. There are two broad classes of WM-loaded activities. In the first, the child has to store a considerable amount of material that may be arbitrary in structure (such as a series of numbers or the precise wording of a fairly lengthy sentence). The second type of activity involves the child storing material while being engaged in another activity that is demanding for him or her (such as spelling or reading a new word or making an arithmetic calculation).

In the following section we discuss ways of managing and reducing the WM demands of such learning situations. Some of these methods are based on good practice by teachers and classroom assistants observed in the course of our study. Other techniques have been derived from current understanding of the cognitive processes of WM. We recommend a remedial approach for children with WM deficits that combines multiple methods as appropriate for particular learning situations. In each case, the aim is to reduce the frequency of occasions in which the child fails a learning activity and so misses a crucial learning opportunity because he or she is unable to meet the WM demands of the situation.

Ensure That the Child Can Remember the Task

To achieve learning success, it is crucial that the child can remember the task set by the teacher. The child's memory for instructions will be enhanced by keeping the instructions as brief and linguistically simple as possible. Because instructions that are too lengthy will not be remembered, it is advisable to break them down into smaller constituents where possible. This will also have the advantage of reducing task complexity, another factor influencing learning success in children with low WM (see later).

One effective strategy for improving memory for task instructions is frequent repetition of instructions. For tasks that take place over an extended time period, reminding of crucial information rather than repetition of the original instruction is likely to be most useful. Probably the best way to ensure that the child has not forgotten crucial information is to ask them to repeat it back. Children have good insight into their WM failures and are able to say they have forgotten if given the opportunity. It has also been shown that attempting to remember information boosts memory performance on subsequent retrieval attempts.

Use External Memory Aids

The child's performance in activities that have a complex structure, or that impose significant processing as well as storage loads, will be aided by the use of external memory aids. These are already in widespread usage within many classrooms. They include number aids such as "Unifix" blocks and number lines that are designed to reduce processing demands.

However, it was apparent in our observational study that children with poor WM function often choose not to use such devices in the context of relatively complex tasks and gravitate instead toward lower-level strategies whose processing requirements may be lower (such as simple counting) but less efficient (e.g., more error-prone and time-consuming). To encourage children's uptake of such aids, we recommend regular periods of practice in the use of the aids in the context of simple activities.

Relevant spellings also function as useful memory aids in writing activities. Reducing the processing load and opportunity for error in spelling individual words will increase the child's success in completing the sentence as a whole. However, reading off information from such external aids was observed, in itself, to be a source of error in children with low WM skills, with children often losing their place within either the word or the sentence. Making available spellings of key words on the child's own whiteboard placed on his or her desk rather than a distant class board will reduce these errors by making the task of locating key information easier and reducing opportunities for distraction. Methods for marking the child's place in word spellings may also be useful because loss of position within a word while copying was a frequent source of error and task abandonment.

Reduce Processing Loads

In complex learning situations that place significant processing and storage demands on the child, the chances of WM failures can be reduced by cutting down the processing load of the task. This will reduce the possibility of task failure as a result of a combination of excessive storage and processing demands. In many situations, this may be achieved easily. Consider, for

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example, the sentence-writing activity that was a source of difficulty for all of the children with low WM that we observed. Processing loads can be diminished by reducing the linguistic complexity of the sentence—in terms either of the vocabulary (common versus lower frequency words) or of the syntactic structures (simple subject–verb–object constructions rather than relative clauses). The planned sentences could also be reduced in length. If the child has to work with lengthy sentences and difficult words, the chances of task failure will increase dramatically and an opportunity for task success, and hence for learning, is lost. Provided that the modified learning activity successfully meets the desired learning outcomes identified by the teacher, this strategy of simplifying processing requirements is likely to be highly effective in promoting successful completion of complex tasks.

SUMMARY

There is substantial evidence that low scores on tests of WM skills are associated with poor attainments in the key curricular areas of English and mathematics. To illuminate the specific nature of the failed learning episodes that may be contributing to the failure of such children to make normal scholastic progress, we observed the classroom behavior of three children with poor WM abilities. Four different kinds of learning failure were observed with high frequency in each of these children that could be attributed to the children failing to meet the WM demands of the activity: forgetting instructions, failing to meet combined processing and storage demands, losing track in complex tasks, and forgetting from episodic long-term memory at high rates.

We propose that these learning failures impair the children's chances of abstracting knowledge and skills that form the basis for functioning in the complex cognitive activities associated with the domains of literacy and mathematics. It is therefore important to identify WM problems as a source of learning difficulty in individual children and to reduce the opportunities for learning failures by minimizing WM demands in classroom activities. In a WM intervention study, we are applying the principles from cognitive psychology to achieve these goals. Children with WM impairments are identified using standardized tools derived from the WM model, such as the Working Memory Test Battery for Children (Pickering & Gathercole, 2001) and the Automated Working Memory Assessment (Alloway, Gathercole, & Pickering, 2004). Classroom staff receive guidance that allows them to identify WM failures in the classroom and shows them how to minimize them for individual children. The children will also be encouraged to use their own strategies to overcome their WM limitations. It is hoped that this approach will enhance learning outcomes for children struggling to cope with poor WM function.

Summary Box

- There is wide individual variation in WM skills during the childhood years.
- Children with poor WM skills usually make poor academic progress in the areas of literacy and mathematics.
- Children with WM impairments frequently fail in classroom activities that impose significant WM loads.
- The most common types of classroom failure involved forgetting instructions, losing place in complex tasks, and struggling in tasks that involved both processing and storage loads.
- Although children with WM impairments have some awareness of their memory problems, in our study their teachers did not and attributed their problems to lack of attention.
- It is proposed that effective management of WM loads in classroom activities may minimize the learning difficulties that usually accompany impairments of WM.

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