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Chapter 3: Cognitive processes and digital reading

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Abstract

Regardless of the medium, reading is a complex skill involving the execution and coordination of many cognitive processes. Reading comprehension in skilled readers is the end-product of processes that are fast, efficient, interactive and strategic. These processes, some of which may be described as lower level (e.g. word recognition) and some as higher level (e.g. inference-making), rely on aspects of executive function including attention, working memory, executive control and metacognition. This chapter examines the involvement of these four aspects in both print and digital reading. We explore how on-screen reading of linear and non-linear text (hypertext) makes additional demands on executive function, potentially threatening comprehension and learning. We also consider how technology may confer processing advantages for readers with particular difficulties. Recommendations aimed at preventing shallow processing when engaging with digital text are presented. Having reviewed the literature, we speculate on how the potential of technology may be harnessed in order to encourage reading, to improve assessment, and to increase knowledge.

1. Introduction

Psychologists and educationalists have studied print reading for more than a century, leading to a significant body of research and a high level of understanding of the cognitive processes involved in skilled reading. As both the amount and quality of digital reading increases, however, there is a need to increase our knowledge of the skills and processes involved in digital reading and to understand how reading digital text impacts cognitive functioning. The introduction of computers, tablets, smartphones and other digital devices into everyday life has transformed how individuals interact with written information. More importantly, these new technologies have made it possible to tailor text in accordance to individual needs and preferences. With rapidly advancing technologies and new features such as Enhanced eBooks - containing embedded media, interactivity, and narration - flooding the market, many questions arise as to how new technologies may impact an individual's ability to engage with written text. As adults, we know experientially that text format can impact the ease of reading and determine whether or not we will engage with text content, for example carrying out sustained reading on an e-reader (Hayler, 2011) or the screen of any digital device. While our level of engagement in these instances may be modulated by complex motivational factors, converging evidence from the fields of typography (Dyson, 2004) and cognitive science (e.g. Coiro, 2015; Koriat, Ackerman, Adiv, Lockl, & Schneider, 2014; Kornmann, et al., 2016; Montani, Facoetti, & Zorzi, 2014) indicates that a multitude of cognitive processes may be influencing these behaviours, and that these cognitive processes are themselves affected by the modality of text display.

Decades of research point to reading being a complex process involving many components that are generally accepted to reflect either lower-level or higher-level processes. The former include word recognition, syntactic parsing and semantic-proposition encoding, while higher level processes engaged in comprehension include updating, inferencing, inhibition, and strategic processing or metacognition. Importantly, all of these processes – both higher level and lower level – operate within the constraints of a limited capacity cognitive system, consuming cognitive resources according to the extent to which they are automatised. When a process is executed automatically it makes minimal demands on working memory, whereas less automatised (i.e. controlled) processes make relatively large demands on working memory (Ashby & Rayner, 2006; Samuels, 2006; Stanovich, 1990). Consider word recognition, for example. Fluent readers recognise words quickly and seemingly effortlessly, leaving significant cognitive capacity for more demanding (less automatic) activities such as inference-making. It should be noted, however, that even higher level processes can become more automatised as reading skill improves and metacognitive experience accrues (e.g. Perfetti, 2007; Reynolds, 2000). In this chapter we focus on how digital reading (in comparison to print reading) is changing the executive function demands of text processing, specifically focusing on attention, working memory, executive control and metacognition. While we would not claim that other more linguistic reading processes associated with e.g. word recognition and syntactic parsing do not differ in any way in print and digital reading, we contend that digital reading makes particular, increased demands on executive processes, a contention we explore here.

The term 'digital reading' can refer to any engagement with a large range of text formats including books, newspapers, magazines, websites, blogs, and forums. As Walker, Black, Bessemans, Boormans, Renckens and Barratt (2018; this volume) highlight, some of these formats are 'fixed' in the sense that the reader can make only minor, if any, adjustments to them in terms of appearance via sizing, etc. (e.g. e-books). In fixed formats, readers typically progress through the text and engage with content in an order determined by the author. In contrast, less 'fixed' formats such as websites may contain hyperlinks which enable readers to engage with content according to their needs, motivations or knowledge at that particular point in time, meaning that a reader may experience the same overall content in different ways depending on their orientation and approach in a specific reading session. The flexibility inherent in hyperlinked text also means that different readers may engage with the content in different ways, rendering an overall text structure that may be more or less similar to that originally envisaged by the author. Of course, digital reading may involve engaging with more than one text or source in any reading session. Salmeron and colleagues (Salmeron, Strømsø, Kammerer, Stadtler, & van den Broek, 2018; this volume) discuss advanced digital reading skills in contexts where readers need to navigate, integrate and evaluate multiple sources. The focus in this chapter is on the reading of single texts, but it should be pointed out that considerable heterogeneity in terms of text length and linearity exists within the experimental stimuli used in the reviewed studies. Four cognitive processes of interest – attention, working memory, executive control, and metacognition – are discussed in discrete sections. It will quickly become obvious to the reader, however, that it is difficult to maintain a clear delineation between the processes, and our discussion of each invariably includes reference to one or more of the others. One consequence of the interrelatedness of concepts is the potential arbitrariness of where we discuss relevant literature. For example, when a reader decides to pause in order to use a dictionary or an online glossary, metacognition, shifting of attentional focus, and updating of working memory are among the many cognitive processes and skills invoked. Our approach to this challenge is to align literature with what might reasonably be assumed to be the predominant concept; for example, while the decision to re-read a section of text due to a self-assessment of comprehension difficulties will have implications for the updating of working memory, we discuss these issues within the context of metacognition. We re-iterate however that it is difficult to discuss the role of any single process in either print reading or digital reading without invoking the involvement of one or more of the others, and we encourage readers to reflect on the multi-componential nature of reading.

The chapter is organised as follows. We commence by considering the role of visual attention in the context of linear text with its relatively static format before discussing how the more dynamic nature of hypertext presents challenges for working memory and executive control. For each cognitive process we summarise what is known about its role in print reading then proceed to discuss parallel research concerning digital reading. We close the chapter with an overview of research on metacognition, highlighting its relevance when reading for learning, problem solving or assessment.

As will become evident when compared with traditional print-based reading, there is relatively little research on digital reading in general, and only a small proportion involving children. Furthermore, within this context it is timely to emphasise that knowledge and understanding of the developmental patterns of relevant cognitive processes are still very much emerging. While advances in knowledge regarding the development of attention, working memory, executive function and metacognition in children and young people have been considerable in the last two decades, we predict significant advances in the next decade as researchers avail of increasingly powerful, and accessible, technologies.

2. Attention

Attention can be seen as a set of guiding selection processes for received perceptual information; these processes restrict the amount of external stimuli being submitted to further processing by the limited human cognitive system, to avoid its overload (Anderson, 2004; Driver, 2001; Carrasco, 2014; Goldberg & Wurtz, 2013; Kandel, 2013; Nobre & Mesulam, 2014). Attention is critical to all aspects of everyday functioning, including meeting basic needs, interacting with others and learning or recalling new information. The term encompasses a range of operations from low-level orienting towards sensory stimuli, through to higher-level processes. The latter can be put into different categories such as attention shifting, divided attention, focused attention, sustained attention, or selective attention (Driver, 2001; Lezak, Howieson, & Loring, 2004; Wagner, Jonides, & Reading, 2004).

Following Broadbent (1958) and Mullane, Lawrence, Corkum, Klein and McLaughlin (2016), successful learning processes comprising effective identification, learning, and memory can only take place if the individual has acquired a sufficient level of sustained attention. Since working memory and attention have limited capacity, they mutually guide each other: whereas memories of experiences influence an individual's decision-making processes on what attention should be drawn to, the regulation of the contents encoded into memory is performed by attention (Chun & Turk-Browne, 2007).

2.1 Attention and reading

Attention can be seen as a prerequisite of effective and successful reading as it enables the individual focus on text content, leading to improved reading performance through practice (Chen & Huang, 2014; Stern & Shalev, 2013). As a volitional and effortful activity, successful reading for meaning relies upon multiple aspects of attention: at a basic level individuals need to be able to orient themselves to visual text and move their attention in the direction of the new information. While reading we have the impression of our eyes moving steadily and smoothly along the lines. However, quite the contrary is the case: as we read our eyes are engaged in an alternating process of short and rapid movements, or saccades, versus fixations (Reichle, Rayner, & Pollatsek, 2003).

Whereas almost no visual information is processed during the short saccadic eye movements (20-50 msec) (Ishida & Ikeda, 1989; Wolverton & Zola, 1983), most information processing occurs in the brief periods (200-250 msec) while the eyes remain stationary (Erdmann & Dogde, 1898; Huey, 1908). The amount of distinct orthographic elements (e.g. letters, letter clusters or syllables) that can be processed in parallel during a single fixation has been termed perceptual span (Rayner, 1998) or visual attention span (Bosse, Tanturier, & Valdois, 2007). Research has consistently shown a close relationship between this span and the development of reading ability, with improvements in reading associated with accompanying increases in the amount of information processed regarding the number and nature of letters to the right of fixation (see Häikiö, Bertram, Hyona, & Niemi, 2009; Rayner 1998, 2008).

Such findings suggest that the act of learning to read itself may contribute towards the refinement of the visual attention skills so integral to the act of reading. However in terms of other aspects of attention needed for successful reading e.g. orienting or sustaining attention, the development of these skills is subject to broader maturational influences which are still in the process of being fully understood. For example, as the prefrontal cortex matures, a process that extends into adolescence, young people are gradually able to apply more cognitive control to their attention (Casey, Giedd, & Thomas, 2000), helping them to refrain from immediate gratification and to focus on working towards future goals (Posner & Rothbart, 2007). These processes are defined as executive processes and determine not only a well-functioning memory and successful learning, but also the effective acquirement of academic skills (Checa, Rodriguez-Bailon, & Rueda, 2008; Posner & Rothbart, 2007).

The majority of researchers studying attentional development in typically and atypically developing children (e.g. Huang-Pollock, Nigg, & Halperin, 2006; Kratz et al., 2011; Mezzacappa, 2004; Mullane, Corkum, Klein, McLaughlin, & Laurence, 2011; Rueda et al., 2004; Sobeh & Spijkers, 2012; Weatherholt, Harris, Burns, &

Clement, 2006) have taken the Attention Network Theory (Posner & Petersen, 1990) as their reference model. The essence of this theory is to define attention as being constituted of three neural networks: alerting, orienting and executive network. While some components of attention develop very early and are relatively matured by the time a child enters formal education, other aspects of attention continue to develop well into middle (7-9 years) and late (10-12 years) childhood (Casey et al., 2000; Posner & Rothbart, 2007; Ridderinkhof, van der Molen, Band, & Bashore, 1997; Rueda et al., 2004; van der Molen, 2000). Alerting, as the ability to reach and maintain an alert state (Posner & Rothbart, 2007), seems to develop in a protracted manner, reaching maturation past middle childhood (Mullane et al., 2016). Orienting, as the ability to move visual attention towards a particular stimulus, seems to mainly develop before the age of 6 or 7 (e.g. Wainwright & Bryson, 2002), with some specific aspects completing maturation towards the end of late childhood (e.g. Iarocci, Enns, Randolph, & Burack, 2009). The executive network is mainly concerned with an individual's voluntary control of attention, with the main function of resolving interferences when there is a simultaneous activation of correct and incorrect responses (Posner & Di Girolamo, 1998). Elementary aspects of executive attention may already be found in infants at the age of 6 to 7 months (Berger, Tzur, & Posner, 2006; Sheese, Rothbart, Posner, White, & Fraundorf, 2008). However, since these higher order processes of guiding an individual's behaviour towards long term goals (Posner & Rothbart, 2007) are executed by the prefrontal cortex of the brain, their development continues through late childhood and adolescence (Band, van der Molen, Overtoom, & Verbaten, 2000; Casey et al., 2000; Mullane, et al., 2016). Based on this model it could be suggested that orienting and executive network potentially play a part in success or failure in reading acquisition.

2.2 Attention and digital reading

The fast-paced development around digital reading has led to research struggling to catch up to answering questions regarding the influence of new technologies on an individual's ability to engage with written text, including the assumed novel demands on attention caused by the introduction of new approaches to reading (Schneps, Thomson, Chen, Sonnert, & Pomplun, 2013a). There are two key ways in which digital reading could potentially impact attention. The first is through changes in the formatting and visibility of text. Traditional print, due to its relative permanence on the page, has developed a uniform set of standard page sizes, font sizes and letter-spacing norms, designed for a hypothetical "average" reader. In contrast, as highlighted in Walker, Black, Bessemans, Boormans, Renckens and Barratt (2018; this volume), digital text is often presented via software that allows for completely individualised modification of print: page brightness contrast, size/spacing or type of font (de Leeuw, 2010; Dyson, 2004; O'Brien, Mansfield, & Legge, 2005), and within a variety of page formats and text window sizes (Schneps, O'Keefe, Heffner-Wong, & Sonnert, 2010; Schneps et al., 2013b; Warschauer, Park, & Walker, 2011). The second key change is the growth of hypertext and non-linear text presentation, compared to the linear presentation common to paper books.

Regarding the impact of digital text formatting on attention, this area has arguably been investigated in most depth in relation to struggling readers, a population who are largely defined by their difficulties in reading traditional print-based text. A recent series of studies by Schneps et al. (Schneps et al., 2010; 2013a,b) has looked at the effect of display screen sizes and consequent varied linewidths on struggling readers' comprehension. It was found that a small, smart-phone sized reading window can facilitate reading comprehension and fluency. The above studies, as well as work by other research groups (e.g. Zorzi, et al., 2012) has found positive correlations between increased inter-letter spacing and improved decoding and comprehension for struggling readers; this is a formatting parameter that has only become more easily adaptable with the increased prevalence of digital text. The advantages for struggling readers of both increased inter-letter spacing and a smaller text window can potentially be explained by the phenomenon of visual crowding (Schneps et al., 2013a), something that can have a particularly deleterious impact for struggling readers (Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Moores, Cassim, & Talcott, 2011; Spinelli, De Lica, Judica, & Zoccolotti, 2002; Zorzi et al., 2012). Crowding can be described as difficulty with recognition of distinct objects, such as individual symbols or letters, when they appear in a clutter (Pelli et al., 2007). Whilst the causes of crowding for struggling readers are still being fully elucidated, psychophysical studies do support the notion that crowding is intimately linked to the allocation of spatial attention (Petrov & Meleshkevich, 2011). With digital design features such as altered letter-spacing and altered text-window size thus allowing us to accommodate for individual differences in basic attention processes, many other opportunities for supporting attention, as opposed to challenging it, may exist.

Regarding the proliferation of hypertext, while later sections of this chapter discuss the implications for executive control and working memory, the ubiquitous presence of blue, underlined words, used to signal hyperlinks, has more basic attentional implications. Eye-tracking research by Fitzsimmons (2017), for example, has shown that the mere presence of a single coloured word within a written sentence will reduce the likelihood that the word is skipped (as long as the colour does not have reduced contrast, e.g. grey – blue does not appear to reduce contrast, Gagl, 2016). When readers know that a coloured word is explicitly a hyperlink that can be clicked in order to provide more information, gaze fixation times show further attentional modulation. In an interesting follow-up study using custom-made hypertext Fitzsimmons (2017) found that gaze fixation time was increased especially when low frequency words contained a hyperlink. Fitzsimmons interpreted this behaviour as reflecting re-evaluation of the prior content, given the potential mismatch between the presence of a hyperlink, suggesting importance, and location of the hyperlink on low frequency and thus potentially less consequential words. This example, however, also shows the close interdependence between lower level cues to information salience and higher levels of both linguistic and metacognitive processing.

In sum, it is clear that the presentation of text in digital formats is altering how we attend to the written word in ways that we are only just beginning to understand. Hypertext, bringing with it the presence of hyperlinks, provides new external markers of text salience that are likely to provide both affordances and challenges to a reader's attentional capacities. Some aspects of digital text appear to have particular attentional benefits for struggling readers, for example the ability to more easily reduce crowding effects, however a lot more work is needed to fully understand individual differences in how attention and technology interact. Implications for comprehension were raised in this section; comprehension is explored further in the next section where we consider the central role of working memory in reading and understanding print and digital text.

3. Working memory

The contribution of working memory to skilled reading and to the development of reading skills has been shown consistently over several decades since Daneman and Carpenter's (1980) seminal work on working memory span and reading comprehension (e.g. Cain, Bryant, & Oakhill, 2004; Gathercole, Alloway, Willis, & Adams, 2006; Leather & Henry, 1994; Nouwens, Groen, & Verhoeven 2016; Seigneuric, Ehrlich, Oakhill, & Yuill, 2000). Research has consistently shown that readers – children and adults – with a high working memory span perform better on measures of comprehension than readers with a low working memory span. We return to this issue later when we consider a number of models of reading comprehension.

The working memory model of Baddeley (e.g. Baddeley & Hitch, 1974; Baddeley, 1986, 2000, 2007) is undoubtedly the most widely applied within the relevant literature. Baddeley and Hitch's model comprises four components – phonological loop, visuo-spatial sketchpad, episodic buffer and central executive. The first two are considered to be slave systems for short term retention and rehearsal of verbal and visual or spatial material respectively while binding of material is purported to be the main function of the episodic buffer. The central executive manages resources and allocates attention. The functions of updating, inhibition, shifting or switching and cognitive flexibility are commonly associated with the central executive (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000); working memory as applied to reading relies heavily on the updating function. It is generally accepted that the phonological loop does not have an important role in skilled reading, regardless of the medium. In contrast, researchers are beginning to identify a role for the visuo-spatial sketchpad in digital reading.

3.1 Working memory and reading

It is widely accepted that reading is the construction of meaning - of comprehending and actively responding to the text being read. When we consider some definitions of reading comprehension, it becomes clear why working memory is an inherent part of the reading process. Durkin (1993) described comprehension as the essence of reading. He defined reading comprehension as "…intentional thinking during which meaning is constructed through interactions between text and reader" (Durkin, 1993, p. 76). Harris and Hodges (1995) defined reading comprehension as "the construction of the meaning of a written text through a reciprocal interchange of ideas between the reader and the message in a particular text" (Harris & Hodges, 1995, p. 39). The transaction between reader and text was also emphasised by both Kucer (2001) and Rosenblatt (1978).

Most text and discourse researchers use the term mental representation to refer to the outcome of text comprehension processes (e.g. Kintsch, 1988, 1998; van den Broek, Young, Tzeng, & Linderholm, 1999). McNamara and Magliano (2009) critically evaluated seven comprehension models in an attempt to uncover the foundations of a comprehensive model of reading comprehension. Two of these models – Construction-Integration (Kintsch, 1988, 1998) and Landscape Model (Linderholm, Virtue, Tzeng, & van den Broek, 2004; Tzeng, van den Broek, Kendeou, & Lee, 2005; van den Broek, Rapp, & Kendeou, 2005; van den Broek et al., 1999) – are particularly relevant here as we consider the involvement of working memory in digital reading (though elements of several other models reviewed by McNamara and Magliano are pertinent too). We also discuss a further influential model, the CC Reader (Just & Carpenter, 1987, 1992).

Kintsch's (1988) construction-integration model is one of the most influential theories of comprehension. In this model, three levels of representation are proposed: surface representation, propositional textbase, and situation model. Kintsch viewed text comprehension as a process of construction, where a reader combines background knowledge with information presented in the text. The resulting levels of representation depend on the reader's purpose. A key component of Kintsch's model is inferencing, an activity which places demands on working memory. As readers progress through text, related knowledge is activated and the reader needs to make decisions about the extent to which inferences and elaborations should be integrated.

The Landscape model (van den Broek et al., 1999) aims to represent the online activation of concepts as a reader progresses through a text. As attentional and working memory resources are limited, the number of concepts which can be active simultaneously is limited, which means that activation will fluctuate as concepts vary in relative importance and relevance during reading. Van den Broek et al. (1999) proposed that activation of specific concepts might result from four potential sources of activation. These are 1) the text currently being read, 2) the text that has just been read, 3) the text read previously, and 4) background knowledge. There is substantial support for the Landscape model and the proposal that readers are constructing a mental representation of text as they read. Although there is insufficient space to consider the supporting evidence here, the Landscape model serves to highlight the dynamic nature of reading.

Of course the construction of a mental representation of text involves much more than inferencing and the activation of background knowledge. Lower level processes such as word recognition, syntactic parsing and semantic-proposition encoding are necessary for comprehension. The Capacity Constrained READER, or CC READER model (Just & Carpenter, 1987, 1992), was developed in an attempt to explain how comprehension is constrained by working memory. This computer simulation of the reading process illustrates how individual differences in working memory capacities impact on reading. According to the model, a number of factors such as syntactic complexity, linguistic ambiguity, memory load, and time constraints can alter the demands made on cognitive capacity which in turn influences reading comprehension performance. For example, higher levels of syntactic complexity or linguistic ambiguity increase demands on the limited capacity of working memory. If capacity is exceeded as a result of one or more of these factors, comprehension suffers. Just and Carpenter (1992) proposed that individual differences in working memory capacity mean that comprehension will be constrained more for some people than for others. Of course reading experiences for many people have changed significantly since their proposals about capacity constraints on comprehension and the development of the CC Reader. We are only beginning to understand how different aspects of digital reading make particular demands on working memory; the remainder of this section highlights some relevant findings from research on both children and adults.

3.2 Working memory and digital reading

This subsection's focus on hypertext reflects historical and recent findings where the majority of researchers have manipulated the complexity of hypertext in their efforts to learn more about the involvement of working memory and other executive functions in digital reading. Hypertexts are non-linear computer-based texts that consist of individual pages connected via hyperlinks (Naumann, Richter, Christmann, & Groeben, 2008). When navigating hypertext, readers click on hyperlinks in order to move from one page to another. Hyperlinks tend to be organised in two main ways - in a hierarchical structure or in a network structure. In the former, each node or page is linked to one above (superordinate) or below (subordinate) whereas nodes or pages can be linked in any way in a network structure. In both hierarchical and network structures, the presentation of information is said to be nonlinear, enabling different readers to encounter the information in different ways as they access pages in a self-directed order by choosing to follow or ignore particular links (Boechler, 2001). In their review of the effect of cognitive load in hypertext reading, DeStefano and LeFevre (2007) suggested that reading and navigating hypertext are likely to place (extra) demands on working memory when compared with traditional linear reading. While the decisions concerning whether and when to follow links will invoke additional metacognitive load, remembering both the navigational steps, as well as the content of multiple nodes will implicate working memory. This contrasts significantly with linear text which requires the reader to make predominantly forward and back decisions alone.

While our focus here is on working memory, the process of hypertext reading - as opposed to reading linear text - is one area where distinctions between working memory and other executive functions such as inhibitory control and switching become more difficult to make. Consider the theories and models presented previously. From the perspective of Kintsch's construction-integration model, building and maintaining a text representation is already demanding; when interruptions to the flow of reading are introduced via the inclusion of hyperlinks and the associated decision-making imposed on the reader, the increased demands on working memory are likely to impact on the development of the representation, thus placing comprehension under threat. Indeed it can also be argued that the cohesion of the text being read can be threatened by the presence of the hyperlinks, making it difficult for the reader to construct a coherent representation, even without the disruption experienced by following hyperlinks. Hypertext by its very nature introduces more interruptions to the reading process, making the role of metacognitive strategies such as comprehension checking and fixing crucial, thus going beyond working memory alone.

In addition to overlapping influences of working memory and metacognition in reading hypertext, there is a growing body of research on the interaction between text structure and reader knowledge in both print reading (e.g. Bohn-Gettler & Kendeou, 2014; Wylie & McGuinness, 2004) and hypertext reading (e.g. Amadieu, van Gog, Paas, Tricot, & Mariné, 2009; Calisir & Gurel, 2003). The main conclusion from studies on print reading is that readers with a higher level of prior knowledge cope better than less knowledgeable readers with texts that are less structured whereas low knowledge readers benefit from more structured text. DeStefano and LeFevre (2007) corroborated these findings specifically in the context of hypertext. They observed that the comprehension of readers with less knowledge of the subject matter of the text was more adversely affected by hypertext than those with a higher level of relevant knowledge. In tandem, there was evidence that readers with lower working memory capacity struggled more with the hypertext than those with a higher WM capacity.

Digital text potentially enables the reader to alter the level of text complexity by choosing to either follow or ignore links. As such, the structure of the text can be under the control of the reader. If high knowledge readers benefit from a lack of structure (e.g. Salmerón, Cañas, Kintsch, & Fajardo, 2005; Salmerón, Kintsch, & Cañas, 2006; Shapiro & Niederhauser, 2004) then creating their own version of the text via hyperlinks may actually enhance their understanding and increase knowledge. In contrast, readers with less prior knowledge will not possess the schema which would enable them to benefit from an exploration of links. Interestingly, however, Calisir and Gurel (2003) found evidence that low prior knowledge readers *did* benefit from hypertext if the text was structured in a way that emphasised the inherent structure of the information. The reading comprehension scores of their low prior knowledge readers were better after reading hierarchical hypertext than after reading a more complicated hypertext (i.e. one containing both hierarchical and network structures) or a linear presentation. This suggests that the complexity of the hypertext is a critical factor when making decisions about its usefulness for readers with higher or lower levels of prior knowledge. Burin, Barreyro, Saux and Irrazábal (2015) assessed the effects of text structure, prior knowledge and working memory capacity on comprehension and navigation of digital text. They showed that low prior knowledge readers are more disadvantaged by network hypertexts than hierarchical hypertexts, and that a combination of low working memory and low prior knowledge results in the weakest performance on a comprehension test. In contrast, high prior knowledge readers can benefit from engaging with network hypertexts where they need to make more of an effort in building a coherent representation; readers with more knowledge looked at more pages, made more non-linear jumps in reading and returned to the home page more often. This pattern of behaviour was also more apparent in individuals with high working memory capacity.

We finish this section with a consideration of the role of spatial working memory in hypertext processing. While previous research has not identified a clear role for visuo-spatial working memory in print (linear) reading (e.g. Seigneuric et al., 2000), some interesting findings have started to emerge from hypertext studies. Kornmann et al. (2016) proposed that multi-perspective hypermedia environments make large demands on working memory, and spatial working memory in particular. Testing 9-12 year-olds, they found that both spatial working memory and the ability to process different perspectives correlated with navigational behaviour. Importantly, children with high spatial working memory capacity were able to engage in effective navigational behaviour leading the researchers to conclude that children with lower spatial working memory capacity would be better served by more linearly structured environments. Pazzaglia, Toso and Cacciamani (2008) investigated the role of verbal and spatial working memory in hypertext navigation in a group of middle school children aged 11-12 years. Children engaged with a geography-learning program - a hypermedium - that enabled exploration of European countries and presented information about geography, politics, economy, culture and society. They interacted with the hypermedium in order to perform two tasks - a semantic task requiring linking of verbal information from across the program, and a mapping task which tapped with visuospatial representation of the multimedia environment. Regression analyses indicated domain-specific involvement in tasks demands, with verbal working memory predicting semantic task performance and spatial working memory having a role in the spatial representation constructed by the children. Jones and Burnett (2007) examined the role of spatial skills in hypertext navigation in 10-11 year-olds. Although not strictly a study about reading, they observed that children with high spatial ability completed tasks in shorter time, became lost less frequently and were able to complete maps of their route through the hypertext more accurately than those with low spatial ability. The influence of navigational skills is examined more fully in Salmeron, Strømsø, Kammerer, Stadtler and van den Broek (2018; this volume).

The role of visuo-spatial ability in hypertext reading by 11 year-olds was investigated by Salmerón and Garcia (2012). Using a hypertext with a navigation overview and a printed linear text, they did not find any relation between visuo-spatial skill and the processing of either text type as measured by performance on comprehension questions requiring the retrieval of information or inferencing. While this finding is unexpected, the authors suggest that the use of such overviews might not increase cognitive (working memory) load, provided that the overview is not very complex in terms of number of nodes and levels. In line with the study by Pazzaglia et al. (2008), they concluded that visuo-spatial skills are involved when the structure of the document or information is not clear but that they are less important when overviews are provided.

In summary, engaging with digital text places considerable demands on working memory. For young readers making the transition from learning to read to reading to learn, visuo-spatial working memory skills appear to be increasingly important. Technology offers authors the opportunity to enhance their text via hyperlinks, resulting in reader engagement with text that has enhanced possibilities for learning but also increased risks for comprehension and learning. As the following sections emphasise, learning from digital text requires a complex interplay of processes, with a reader's progression through text involving – ideally – a constant monitoring of their expectations, goals, success and difficulties. This monitoring draws on an individual's metacognitive ability – their ability to be aware of, and to act on, their own thinking. Effective updating of working memory in order to build a mental representation of the text being read demands inhibition of irrelevant or less relevant information, mental shifting ability and metacognitive skill.

4. Executive control

Executive function is a broad term that encompasses many higher order skills necessary for independent, goal-directed behaviour, including holding and manipulating information in working memory, planning/sequencing multi-step tasks, and ascertaining the 'big picture' from a complicated set of details (Denckla, 1989). It can also include metacognition, or 'thinking about thinking', which is explored further in the next section of this chapter. Cognitive control thus supports flexible behaviour by selecting actions that are consistent with our goals and appropriate for our environment (Badre, 2008). Having already considered attention and working memory, we focus now on other aspects of executive function.

4.1 Executive control and reading

Sub-processes of executive control that are important for reading include directing cognitive processes (Gaskins, Satlow, & Pressley, 2007; Schumacher, 1987), prioritizing (Gaskins et al., 2007), metacognitive monitoring and self-checking (Gaskins et al., 2007), selecting and choosing (Schumacher, 1987), and shifting, organising and managing (Gaskins et al., 2007) one's actions and behaviours. In addition, a sub-component of executive function playing a crucial role in reading comprehension is planning (Gaskins et al., 2007; Schumacher, 1987; Sesma, Mahone, Levine, Eason, & Cutting, 2009). After controlling for commonly acknowledged contributors to reading comprehension (i.e., attention, decoding skills, fluency, and vocabulary), executive control seems to make a significant contribution to reading comprehension but not to word recognition skills (Sesma et al., 2009). Although reading comprehension requires good linguistic skills, successful comprehension is also thought to depend on higher level executive skills such as reasoning, critical analysis and effort allocation across various sections of the reading task (see Bjork, Dunlosky, & Kornell, 2013, for a review; Vellutino, Scanlon, & Lyon, 2000). Hence, executive control includes a set of higher level cognitive processes allowing readers to manage and direct word recognition and comprehension processes.

4.2 Executive control and digital reading

Reading and studying in linear (printed) text contexts includes, for example, choosing to read one section of material carefully whereas only skimming another, choosing to underline one sentence but not another, and choosing one interpretation of a complex topic and ignoring another (Schumacher, 1987). These same processes of utilising executive control are also important in digital reading environments, thus there is no need for total replacement of offline reading strategies with newer online reading strategies, but rather the need for extension and diversification of previous reading processes (Coiro, 2015). However, different digital reading environments, such as search engines, websites, virtual gaming environments, and blog interfaces will create additional executive control demands for readers, for example, paying attention to context cues in choosing the most effective reading strategy for a prevailing context (Coiro, 2015). Thus, in digital learning contexts, comprehension of information requires purposeful, critical and flexible mindsets from learners (Coiro, 2015).

As noted already, in digital reading environments, especially hypertexts, readers need to construct their own navigational pathways through hyperlinked texts (Coiro & Dobler, 2007; Coiro, 2015). This process presumes at least four different cognitive strategies, all of which are sub-processes of executive control: planning, predicting, monitoring and evaluating (Coiro & Dobler, 2007). The strategies in digital contexts can be very similar to the strategies readers use in reading printed text (Coiro, 2015): they plan and make predictions, monitor their understanding and evaluate their responses during and after reading. However, printed texts are usually longer and readers do not have to conduct this self-regulated cycle so often. In online environments, readers encounter continuously new series of hyperlinks, which force them over and over again into the cycle of planning, predicting, monitoring and evaluating. Planning directs readers to consider selection and effective choosing of online sources. For instance, the internet presents a place where learners are connected with an unlimited amount of sources representing different global perspectives (Coiro, 2015). Digital reading involves, though, more than just collecting information; readers also need to prioritise and select between different sources. In digital reading environments, cognitive abilities connect with multiple source comprehension skills, a term by which Goldman et al. (2013) mean selection, coordination and synthesis of information that comes from multiple sources.

Multiple source comprehension skills are especially involved in a specific case of reading in digital media, namely information seeking, which includes goal-directed web-searches. Information seeking also involves other aspects of executive control, such as predicting, monitoring and evaluation. Generally, information seeking consists of five processes: 1) constructing the problem or setting goals for the web search task, 2) reading to locate relevant information by employing adequate search queries (involves predicting), analysing search results and scanning efficiently for relevant information within the Web sites (involves monitoring), 3) reading to evaluate information critically, 4) reading to synthesise information within and across different sources (involves multiple source comprehension), and 5) reading to communicate information (Cho, 2013; Coiro et al., 2007; Guinee, Eagleton, & Hall, 2003; Kiili, Laurinen, & Marttunen, 2008; Kiili, Laurinen, Marttunen, & Leu, 2012; Leu, Kinzer, Coiro, & Cammack, 2004; Leu, Kinzer, Coiro, Castek, & Henry, 2013; Rouet, 2006). As a reminder, however, our approach in this chapter is to restrict our focus to reading single texts; processing issues associated with multiple sources are discussed more fully in Salmeron, Strømsø, Kammerer, Stadtler, and van den Broek (2018; this volume).

Executive control processes such as shifting mindsets flexibly (Gaskins et al., 2007) might also be essential in digital reading comprehension. For instance, the contexts of online reading environments are multiple and rapidly changing, requiring learners to monitor their own actions, and to move between reading-to-locate processes (e.g. skimming search results) and deeper processes of meaning construction (e.g. when finding a relevant source). In addition to executive control processes such as shifting, learners need to employ inhibition control in digital reading environments. They need to learn to pay attention to relevant materials and resist distractions. Of course the nature of the online reading environment also requires multiple physical actions, such as typing, clicking and scrolling, though these actions are performed mostly automatically and at an unconscious level when these skills are fluent.

The increased use of digital learning environments, and especially simultaneous use of different kinds of technologies, has aroused worries concerning the effects of daily media multitasking (MMT) on our cognitive control. Small, Moody, Siddarth and Bookheimer (2009) compared brain activation while reading printed and online text in participants with internet searching experience and participants who did not have such experience. Interestingly, those with previous internet searching experience and those without prior experience show similar brain activation while reading typical text (Small et al., 2009). However, during an internet search task those without prior experience showed similar activation patterns as during reading, whereas experienced participants showed activations in larger brain areas (i.e. in frontal pole, right anterior temporal cortex, cingulate cortex, and hippocampus). Such findings, along with other recent brain research on multimedia use (for a review, see Loh & Kanai, 2015) have led some researchers to suggest that increased everyday MMT might have a negative effect on our executive control abilities, leading to the development of a shallow mode of learning, which is characterised by quick scanning, reduced contemplation, and memory consolidation (Loh & Kanai, 2015). For instance, when individuals are distracted by the multiple streams of media, heavy media multitaskers seem to have more problems with concentration and attention than those who multitask infrequently (Ophir, Nass, & Wagner, 2009).

Results relating to multitaskers are inconsistent, however (see e.g. Minear, Brasher, McCurdy, Lewis, & Younggren, 2013, who failed to replicate the results of Ophir et al., 2009), and the effects of multimedia and internet usage have been questioned due to the lack of conclusive and empirical data (De Bruyckere, Kirschner, & Hulshof, 2016). A recent study including both behavioural testing and functional magnetic resonance imaging by Moisala and colleagues (2016) seems to suggest that adolescents' extensive daily multimedia use is associated with behavioural distractibility and increased recruitment of brain areas involved in attentional control. However, increased multimedia usage has also been associated with forms of attention control where better integration of multiple sources of information, but poorer inhibition of distractors have been observed (Loh & Kanai, 2015). The role of distractors, such as static or video advertisements, is not, however, straightforward. Recent results suggest that readers may learn to avoid being distracted by these visually salient distractors (see Simola, Hyönä & Kuisma, 2014) or that the effect of advertisements depends on the task the reader is performing (Pasqualotti & Baccino, 2014). Overall, findings on the impact of internet use, multimedia use and task-switching performance are inconsistent and more research is needed.

In summary, executive functions have an essential role in reading, with recent research suggesting that the processing of digital text requires an even greater involvement of these functions. At the same time, there is growing concern about how our multi-media environment is affecting our ability to focus our attention, to inhibit less relevant information in any context and, generally, to invest appropriate mental resources in order for successful learning to occur. As the following section will demonstrate, digital technology appears to affect readers' ability to make accurate judgements about their learning, as well as about the effort that needs to be expended if the benefits of technology are not to become threats to learning.

5. Metacognition

Metacognition is 'cognition about cognition' (Furnes & Norman, 2015). As highlighted in the previous section, metacognition is involved in the monitoring and control of various cognitive activities (e.g. Koriat, 2007; Metcalfe, 2000). Flavell (1979) distinguished between three facets, namely, metacognitive knowledge, strategies and experiences. Metacognitive knowledge is the individual's stored knowledge or beliefs about themselves and others as cognitive agents, about tasks, about actions or strategies, and about how all these interact to affect the outcomes of any sort of intellectual enterprise. Metacognitive experiences are conscious cognitive or affective experiences that occur during the enterprise (Flavell, 1979). Metacognitive strategies are used to control cognition in order to achieve a goal (Efklides, 2008). In this final section of the chapter we highlight the crucial role of metacognition in reading and conclude with some educational recommendations.

5.1 Metacognition and reading

Researchers have established the importance of metacognitive knowledge for reading in children (e.g. Anderson & Armbruster, 1984; Baker & Beall, 2009; Roeschl-Heils, Schneider, & van Kraayenoord, 2003) and adults (for review, see Baker, 1989). Findings across age groups indicate that better readers (i.e. comprehenders) appear to have better control of their cognitive activities during reading, and that they seem to engage in more appropriate behaviours such as re-reading, integrating information, planning ahead and making inferences (Anderson & Armbruster, 1984) than less skilled readers. Of particular relevance to our current focus is Baker's (1989) conclusion that while better adult readers demonstrate metacognitive skill in terms of awareness and management of their cognitive abilities, there is considerable room for improvement.

One example of a model of reading where metacognition has an integral role is Walcyzk's compensatory encoding (C-EM) model (1995, 2000) which proposes that individuals can engage in two types of activities if they encounter a difficulty while reading - compensatory behaviours and compensatory strategies. Compensatory behaviours, which include pausing and looking back, are fast, fix-up activities which should involve minimal disruption to the reading process. In contrast, compensatory strategies such as re-reading are more time-consuming activities which disrupt the flow of reading and are likely to impact mental representation. Although Walcyzk did not distinguish between print and digital text when developing his C-EM model, his ideas about the impact of compensatory behaviours and strategies are relevant in both contexts.

5.2 Metacognition and digital reading

The reading experience of children and adults has markedly changed since the influential work of Anderson and Armbruster (1984), Paris and Oka (1986) and Baker (1989). This chapter has already considered how the processing of digital text, and hypertext in particular, imposes higher cognitive demands than does printed text. Given a widely acknowledged need to improve metacognitive knowledge with regard to print reading in order to improve comprehension and learning, we now review evidence relating to metacognition within a digital context that includes reading for problem solving and assessment.

Aspects of executive function that are often overlooked in the context of computerised learning are learners' metacognitive knowledge and the effectiveness of their metacognitive strategies. Finding that the mere presence of an e-book near learners hindered recall of studied information, Morineau, Blanche, Tobin and Guéguen (2005) suggested that electronic devices provide a contextual cue that leads to shallower processing, resulting in inferior cognitive performance. Regulatory decisions, such as activating in-depth processing of the to-be-studied materials and deciding when to stop learning, are at the focus of metacognitive research in this domain. According to this approach, there are two levels of processes involved while facing any cognitive challenge, the object-level and the meta-level (Nelson & Narens, 1990). In particular, while learning, object-level processes involve the transfer of information from an external source to the learner's memory system. The meta-level of learning regulates the object-level processes by setting goals, deciding among appropriate strategies, and terminating activities, based on spontaneous subjective assessment, or monitoring, of one's own knowledge (see Bjork, Dunlosky, & Kornell, 2013). Indeed, empirical studies dealing with memorisation and reading comprehension tasks have shown a causal link between monitoring output and decisions regarding allocation of study time (Metcalfe & Finn, 2008; Thiede, Anderson, & Therriault, 2003).

Only a few studies have directly examined the effects of the reading medium on metacognitive strategy use. Ackerman and Goldsmith (2011) compared metacognitive monitoring and control during learning on screen to that which takes place on paper with a population of undergraduate students who had a strong preference for reading on paper. Screen learners showed screen inferiority: compared with paper learners, they achieved lower test scores along with a more pronounced overconfidence. As subjective confidence directs regulatory decisions, overconfidence is undesirable (Dunlosky & Thiede, 1998; Greene & Azevedo, 2007; Winne, Hadwin, & Perry, 2013). Replicating the study in a population of undergraduates who had only moderate paper preference, Ackerman and Lauterman (2012) found that screen inferiority could be eliminated but only when time pressure was not imposed; mild time pressure appeared to disrupt metacognitive strategies. Notably, participants' predictions of their own success rates on screen did not reflect variations in performance in light of the time frame. This insensitivity of judgments for screen, but not for paper, was also found recently with a brief problem-solving task which takes only 1-2 minutes to perform (Sidi, Ophir, & Ackerman, 2016; Sidi, Shpigelman, Zalmanov, & Ackerman, in press), the results of which suggest less effective metacognitive monitoring on screen than on paper, regardless of the reading burden involved and task duration. The authors also considered individual differences in beliefs regarding the effectiveness of learning on screen versus on paper. Interestingly, they found that medium preference was associated with metacognitive processes such that the best calibration was achieved by those who studied on their preferred medium, regardless of the study medium. Lauterman and Ackerman (2014) suggested two effective and simple to apply methods for eliminating screen inferiority: i) gaining experience with the challenging reading comprehension task, and ii) asking participants in advance to produce keywords summarising the text's essence.

On the one hand, this review brings the good news that media equivalence is possible, regardless of reader preference. On the other hand, the findings of screen inferiority under time pressure in readers who did not expect it to be as strong is worrying. Screen inferiority under time pressure is particularly problematic in educational and admissions exams which include reading comprehension tasks and are often conducted online (e.g., Graduate Management Admission Test, GMAT). It is particularly troublesome in light of the findings regarding dependency in medium preference, as it means that the relative grade is expected to be affected by the match between the testing medium and participants' preferences. Still, it should be noted that screen inferiority has been found only when task characteristics legitimated shallow processing. This was the case under time pressure and when the problem-solving task was presented as a preliminary phase before another task (e.g. Sidi, et al., in press). These findings are in line with the notion that computerised environments provide contextual cues eliciting shallow processing, as suggested by Morineau et al. (2005). However, they carry more hope, because they provide guidelines for eliminating this problem - framing the task as important and doable.

Understanding the conditions under which screen inferiority is expected may aid interpretation of the mixed results regarding media effects found in the literature. First, media equivalence is expected when participants adopt an active mode of processing. For example, this is the case with text editing (Eden & Eshet□Alkalai, 2013; Hargis et al., 2017). Second, imposing a limited time-frame may result in equivalence between the media in test scores and overconfidence (e.g. Norman & Furnes, 2016; though Ackerman & Lauterman (2012) found that restricted time did not remove screen inferiority). Third, asking participants to make fine-grained (i.e. for individual concepts) judgments about their learning may result in more accurate assessments than when they are required to reflect on their learning from larger sections of text (Vössing & Stamov-Roßnagel, 2016). It is possible that as individuals' metacognitive experience with screen-learning increases, they will be better able to engage metacognitive strategies which enable them to overcome screen inferiority.

We are not aware of studies which have directly examined media effects on monitoring and self-regulation of effort among children. However, research suggests that metacognitive knowledge develops throughout the school years (Koriat et al., 2014). Given that the studies above found association between improvement in learning *per se* and improvement in metacognitive strategies, methods for recruiting in-depth processing are expected to promote both aspects also when considering children's computerised learning. Thus, in line with the literature reviewed above, methods which engage students with in-depth processing on screen are expected to be effective.

The increased use of computerised study environments in schools should be considered in light of the literature reviewed above. First, studies repeatedly show that even when K-12 students perform tasks which at their surface level look identical to their paper versions, they often achieve lower performance on screen than on paper (e.g., Mangen, Walgermo, & Brønnick, 2013). Second, there are indications that students, even those who study in paperless classes, still prefer paper reading, at least for some of their daily reading tasks (Seok & DaCosta, 2016; Shonfeld & Meishar-Tal, 2016). Third, technological advances do not yield the large differences that many people still expect. For instance, a salient feature of iPads is that the readers should get a reading experience which mimics paper yet comparisons between laptop computers and iPads often reveal no differences in reading comprehension, mental workload, and even attitudes (e.g., Janjua, 2016). While studies using up-to-date teaching methodologies, like those involving games installed on mobile devices, have identified an increase in enjoyment and motivation, they have not always found improved performance relative to traditional learning methods (e.g., Furió, Juan, Seguí, & Vivó, 2015). Moreover, the use of games, even when successful in study outcomes, does not provide generalisable learning skills of comprehension in other learning tasks that schooling aims to develop. Finally, scientific studies across various disciplines highlight the direct and indirect negative effects of computerised learning on human cognition, learning, and behaviour (see Selwyn, 2015, for a review). Nevertheless, educational systems are predicted to continue the adoption of technology. Thus, our review should not lead to the conclusion that computers are harmful in general, but should direct efforts to finding conditions that allow effective learning on screen (see Gu, Wu, & Xu, 2015; Nichols, 2016, for reviews). In particular, we encourage teachers to be active in engaging students in computerised learning so that they may adapt their learning behaviour to the advantages of this environment in an effective manner.

Our review of research on metacognition showed that individuals tend to engage in relatively shallow processing when reading and working in a digital context.

Several approaches can be taken into consideration when considering methods for recruiting in-depth processing in computerised environments. First, the transfer of effective methods from paper to a computerised environment is relatively easy to implement. Indeed, when students engage in reading comprehension tasks, they often use tools which are also available on paper (e.g., highlighting), even in the presence of tools with clear advantages for computerised learning (e.g., looking up unfamiliar terms via online dictionaries, Van Horne, Russell, & Schuh, 2016; Molin & Lantz-Andersson, 2016). A second approach is to employ methodologies for triggering in-depth processing which are opened up by the technology. For instance, Yang, Hwang, Hung, and Tseng (2013) employed concept maps on mobile devices to support learning of 6th graders from a printed science book. This method was more effective than learning from the book alone and the children showed a high level of acceptance of this tool. Finally, a unique advantage of computerised environments is the ability to adjust the learning tasks to each individual student's strength and weaknesses (Shute & Towle, 2003; see Özyurt & Özyurt, 2015, for a review). For instance, when Mustafa and Sharif (2011) employed a system adapting educational materials to the student's learning style they found better academic achievements among students who learned in line with their personal learning style than among those who studied the regular curriculum (see also Dolenc & Aberšek, 2015).

In a nutshell, readers and learners appear to behave differently when engaging with printed versus digital presentation of texts for learning and for problem solving. As computer-based learning environments are unlikely to disappear, overcoming screen inferiority should be a high priority for researchers and designers of modern study environments. The reviewed literature suggests that computerised learning and problem solving can be as effective as on paper, but that people spontaneously tend to use shallower processing on screen. Encouragingly, there is evidence that this is not inevitable, and that readers, if guided properly, can adapt more active engagement which can be expected to result in enhanced learning outcomes.

6. Conclusions and future directions

In today's classrooms and homes, children and young people are expected to acquire efficient reading skills in a digital environment which presents opportunities as well as challenges. Technology can be at the same time engaging and distracting, meaning that readers need to develop robust metacognitive skills as they negotiate an interactive, on-screen environment. It will be apparent from our review of existing literature that we are only beginning to understand the cognitive demands of processing digital text, and that more research is needed on all of the processes and skills addressed in this chapter. Within the particular context of hypertext, we concur with DeStefano and LeFevre's (2007) suggestion that a model of learning from hypertext should incorporate prior knowledge, working memory capacity and the ability to impose structure on information. Recent work on metacognition demonstrates the influential role of metacognitive awareness in all interactions with digital text. In the decade since DeStefano and LeFevre's review, opportunities for digital reading have increased in quality and quantity, and there is a clear need for a better understanding of how readers engage with digital text, and of how different types of digital text challenge and support different readers.

No-one would deny that several influential models of reading have served researchers, educators and policy makers well in terms of explaining what reading involves and in permitting predictions about performance and outcomes. It should be recognised, however, that none of these models were intended to describe or facilitate predictions about reading digital text in any of its guises. Notwithstanding the challenge of doing so, we suggest that the goal of research in the next decade should be to consider whether, and to what extent, our existing conceptualisations of the reading process are appropriate for the digital environment. Where they cannot explain the intricacies of reading in the twenty first century, new conceptualisations will be required.

On the flip side, we suggest that an increase in knowledge about the role of cognitive processes in reading might inform the development of digital technology and its associated potential. It is not inconceivable to imagine that text might be adaptable on several dimensions according to the needs or preferences of a reader. Given what we know about i) the operation of executive functions within a limited capacity cognitive system, ii) the influence of linguistic and world knowledge, and iii) reader motivation and engagement, it might be desirable for digital reading environments of the future to be flexible beyond design features already discussed in this chapter such as font and window size. Dimensions on which text might be increasingly adapted in order to match reader characteristics include linguistic and structural complexity, length, as well as the extent to which text content is presented independently or integrated with other sources (e.g. links to other e-books, for example). Armed with meta-cognitive knowledge readers might be able to tailor a text in line with their relative strengths and weaknesses in various aspects of executive function, as well as their relevant prior knowledge in order to increase its accessibility, relevance and interest in a given context. While any such flexibility would require significant technological advances, (not to mention further progress in our understanding of individual differences in reading) we speculate that at least two levels of adaptability might be achievable in the future. At a generic level readers would indicate their preference for text suitable for a particular purpose, e.g., reading to entertain, reading for information searching, or reading to evaluate and critique. At a personal level, readers might be able to drive text adaptations through provision of data about their working memory capacity, their tendency to be distracted, etc. Teachers and parents might avail of opportunities to vary texts for children on dimensions relating to challenge or engagement, for example. Such actions would help realise one of the exciting affordances that digital reading can offer: an unprecedented opportunity to individually tailor reading material to the skill and interest profile of each unique reader. This alignment of literacy and the individual is explored further in Ben Yehudah, Hautala, Padeliadu Antoniou, Petrova, and Leppänen, (2018, this volume).

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