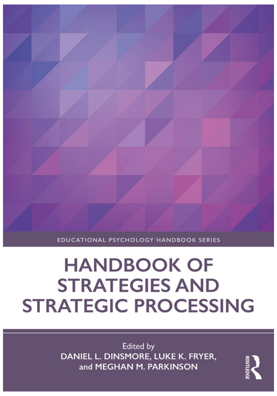

Handbook of Strategies and Strategic Processing

Daniel L. Dinsmore, Luke K. Fryer, Meghan M. Parkinson

Measuring Processing Strategies

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9780429423635-19
Leen Catrysse, David Gijbels, Vincent Donche
Published online on: 10 Feb 2020

19

MEASURING PROCESSING STRATEGIES

Perspectives for Eye Tracking and fMRI in Multi-method Designs

Leen Catrysse, David Gijbels, and Vincent Donche
UNIVERSITY OF ANTWERP, BELGIUM

Many educational researchers argue that the main aims of educational research are understanding and enhancing the quality of learning and processing (Dinsmore, 2017; Vermunt & Donche, 2017) and researchers are therefore looking for appropriate methods in order to capture students' learning and processing. Until now, empirical research on students' processing strategies in higher education has mostly focused on the use of self-report measures (Dinsmore & Alexander, 2012; Fryer, 2017; Vermunt & Donche, 2017). In early work on students' processing strategies during learning from texts, interviews were used (Marton & Säljö, 1976) and, later on, concurrent think-aloud protocols (Fox, 2009; Pressley & Afflerbach, 1995). Following this early work, self-report questionnaires were used to gain insight into students' general disposition towards processing strategies (Biggs, 1987, 1993; Entwistle & Waterston, 1988; Vermunt, this volume). There has thus been a shift from measuring processing strategies at a task-specific level to measuring students' general disposition towards processing strategies. Researchers in the field agree on the variability of processing strategies over learning tasks, but most empirical research is conducted at a more general level, thus ignoring this variability at the task level (Fryer, 2017; Vermunt & Donche, 2017).

More recently, with the advent of new psychophysiological measures, such as eye-tracking and functional magnetic resonance imaging (fMRI), there is a renewed interest in examining the task-specific processing strategies during a learning task. These online measures can be used during the execution of a learning task and are able to capture both conscious and unconscious processing activities. The advantage of these psychophysiological measures is that subjects cannot consciously manipulate their responses in comparison with self-report measures where this could be happening (Dimoka et al., 2012) and that they can register the micro-processes of learning (e.g., how information is integrated between words and sentences). As will be demonstrated later in this chapter, some micro-measures are more strategic and conscious in nature than other micro-measures. Self-report measures are only able to capture these strategic and conscious processes, while psychophysiological measures can capture both strategic and more automatized processes during learning.

In this chapter, we will give an overview on how eye tracking and fMRI can be used to examine students' processing strategies in relation to learning from verbal material (i.e., words, paragraphs and texts). We will discuss the opportunities of these measures and show what they can and cannot tell us about processing strategies. In addition, the challenges will be discussed of using these psychophysiological measures in relation to processing strategies. In a final step, we will give our view on how this field can move forward and what we can take away from this chapter.

OPPORTUNITIES

Can Eye Movements Shed Light on Processing Strategies and Strategy Use?

In eye movement registration the location of the eye gaze is recorded with short time intervals (e.g., a low-precision eye-tracker with a sampling frequency of 60 Hz collects pictures of the eye gaze every 16.67 milliseconds, and a high-precision eye-tracker with a sampling frequency of 1200 Hz collects pictures of the eye gaze every .83 milliseconds). In a next step, the location of the eye gaze is related to the stimulus a participant is looking at (e.g., a text, a picture, a video, a questionnaire). This technique allows us to investigate to what parts of the learning material a student allocates visual attention and for how long (Holmqvist & Andersson, 2017). Eye movement research has been used extensively to better understand reading processes at the word and sentence level, the text level and the level of multiple documents (Hyönä, Lorch, & Rinck, 2003; Jarodzka & Brand-Gruwel, 2017; Rayner, 2009). Eye movement research focuses on the micro-processes of reading (e.g., how much time is needed to process certain words and from which word a reader starts rereading a sentence). Theorists have emphasized that the text-related processing strategy adopted by a reader/student will have strong effects on micro-processes and on the construction of the mental representation (Hyönä, Lorch, & Kaakinen, 2002; Kintsch, 1998; Kintsch & van Dijk, 1978). Focusing on text learning, first pass and second pass reading times are often used as eye movement duration measures (Hyönä et al., 2003; Jarodzka & Brand-Gruwel, 2017). First pass reading time refers to the summed duration of all the fixations on the target region (e.g., a sentence) before exiting it. Second pass reading time refers to the duration of all regressions back to the target region (e.g., a sentence) after the first pass reading time has been terminated (Hyönä et al., 2003). First pass reading times are an indication of early processing and object recognition (Hyönä et al., 2003). Second pass reading times or rereading times reflect processes happening later in comprehension (Holmqvist & Andersson, 2017), such as high-level or deeper cognitive processing (Ariasi & Mason, 2011; Holmqvist & Andersson, 2017; Penttinen, Anto, & Mikkilä-Erdmann, 2013) and attempts to reinstate text information into working memory in order to elaborate on it or rehearse it (Hyönä & Lorch, 2004). Second pass reading times are thus more strategic in nature than first pass reading times.

Different student characteristics shape how students build up their mental representations during text learning (Alexander & Jetton, 1996; Fox, 2009; Jarodzka & Brand-Gruwel, 2017). Influential models on deep and surface processing strategies and strategy use stress the importance of the interplay between learner characteristics and the nature of that processing or strategy use (Alexander, 1997; Dinsmore & Hattan, this volume; Richardson, 2015; Vermunt & Donche, 2017). Important learner characteristics that affect the nature of processing during learning are the students' general disposition towards strategy use, interest, motivation, prior knowledge, working memory capacity, personality, regulation and emotions (Baeten, Kyndt, Struyven, & Dochy, 2010; Vermunt, 2005; Vermunt & Donche, 2017). Students' general disposition towards deep and surface processing strategies can have an important influence on how they learn from texts (Kirby, Cain, & White, 2012), especially on what they perceive to be relevant or important in the text (Kendeou & Trevors, 2012). The study of Catrysse et al. (2018) combined general self-report questionnaires on deep and surface processing strategies with eye tracking data of reading one expository text. They showed that students with a general disposition towards combining deep and surface processing strategies, as measured with self-report questionnaires before reading the text, reread the text more thoroughly than students who were lacking in the use processing strategies, as reflected in longer second pass fixation durations. We believe this reflects the uni-dimensional effect of the students' general disposition towards processing strategies on their actual processing during learning from a text. However, the study of Catrysse, Gijbels, and Donche (2018) provided evidence for the multidimensional nature of strategy use during text learning. In this study, general self-report questionnaires on deep and surface processing strategies, task-specific cued retrospective think-alouds and eye tracking were combined. They showed that highly interested students, who use deep processing strategies (both as measured with a general self-report questionnaires and cued retrospective think-alouds), reread key sentences in a text for longer than detailed sentences and thus process these key sentences more deeply. The study did not take students' learning outcomes into account, so it is unclear whether processing these key sentences more thoroughly was related to better reading comprehension. This study emphasizes the importance of the interplay between processing strategies and other learner characteristics in order to fully understand the micro-processes of learning. In addition, it shows that the selectivity in processing information in the text is the result of a more complex interplay between different learner characteristics and is not solely determined by processing strategies. Although this was already assumed in theoretical frameworks and empirical research focusing on learning outcomes (Alexander & Jetton, 1996; Schiefele, 1996, 1999, 2012; Schiefele & Krapp, 1996), eye movement registration now allows us to show these effects during the online learning and reading process.

Early work on eye movements and vision showed the important influence of the learning task on participants' eye movements (Yarbus, 1967). Also, reading and learning from a text may occur with diverse tasks in mind, such as reading in order to give a presentation, reading in order to answer closed-ended questions, reading in order to answer open-ended questions, reading for entertainment, reading in order to find relevant information, etc. (Kaakinen & Hyönä, 2005, 2007; Kaakinen, Hyönä, & Keenan, 2002; Yeari, Oudega, & van Den Broek, 2016; Yeari, van Den Broek, & Oudega, 2015). In addition, researchers examining students' processing strategies agree that one of the most salient contextual variables influencing processing strategies is the assessment method. This is also known as the backwash-effect of assessment (Baeten et al., 2010; Gielen, Dochy, & Dierick, 2003; Segers, Nijhuis, & Gijselaers, 2006). The study of Catrysse et al. (2016) showed that the assessment demands influence how the students process different types of information in the text. More specifically, students who were expecting reproduction-oriented questions processed the details more thoroughly and repeated these details more often. However, students in the deep condition did not look longer at essentials in the text, but this can be explained by the fact that incorporating key information in the mental representation can be achieved mentally, or can result in overt behavior in which students actively reread essential parts (Hyönä et al., 2003; Kaakinen & Hyönä, 2008). Other research showed that key information or central ideas in the text are learned regardless of strategy use and are necessary for building a mental representation of the text (Lonka, Lindblom-Ylänne, & Maury, 1994; van Dijk & Kintsch, 1983). In other eye-tracking studies on students' processing strategies, all students received the same instruction for learning the text, namely, they needed to learn the text in order to answer questions on the content afterwards. It was not further specified which type of questions students could expect (Catrysse et al., 2018). Therefore, it may come as no surprise that students processed details and key sentences in a similar way in order to prepare for all kinds of questions. In another study, all students received the instruction to study the text material like they would do when preparing for exams. Again, it was no surprise that students using different processing strategies were not selective in processing key sentences and details, as the learning task was quite general (Catrysse et al., 2018).

Is fMRI a Bridge Too Far?

With regard to brain imaging methods, there has been an explosion in neuro-educational research since the beginning of the 21st century (Huettel, Song, & McCarthy, 2014). Brain imaging methods are used to localize deep and surface processing strategies in the brain, more specifically, to examine which brain regions are activated during deep and surface processing strategies (Galli, 2014). In 1997, Bruer published a paper in which he claimed that neuroscience was a bridge too far for educational research (Bruer, 1997), meaning that we cannot draw implications for educational practice directly from neuroscientific research. However, together with other researchers, he believed that a two-way path is possible in which education can be linked to cognitive science in fields such as educational and cognitive psychology, and cognitive science can be linked to neuroscience (Bruer, 1997; Mason, 2009; Mayer, 1998). And as student learning takes place in the brain, neuroscience is a relevant research area to examine further (Mayer, 1998). In the educational psychology literature, researchers have emphasized that we should not see deep and surface processing strategies as a pure dichotomy, but rather as being at the ends of a continuum (Dinsmore & Alexander, 2016; Lonka, Olkinuora, & Mäkinen, 2004). Most of the time students combine several processing strategies while learning, and, consequently, how students learn cannot by characterized by one single processing strategy (Donche & Van Petegem, 2009; Vanthournout, Coertjens, Gijbels, Donche, & Van Petegem, 2013). Previous eye movement studies in the field have also provided evidence for the fact that deep and surface processing strategies are often combined when learning (Catrysse et al., 2016, 2018; Catrysse et al., 2018). Neuroscientific research can provide more insight into whether differences between deep and surface processing strategies are qualitative (i.e., activations in different brain regions) or quantitative (i.e., overlapping brain regions but with differences in the level of activation) in nature (Galli, 2014). More specifically, it has the opportunity to indicate whether deep and surface processing strategies are overlapping constructs or not (Catrysse, Gijbels, & Donche, 2019).

In accordance with what other researchers have mentioned as being challenges for neuroscientific research (Mason, 2009; Mayer, 1998; Varma, McCandliss, & Schwartz, 2008; Willems, 2015), processing strategies have mostly been examined using very basic learning tasks at the word level (Catrysse et al., 2019; Galli, 2014). Subjects receive deep-level and surface-level learning tasks in order to evaluate words when they are being scanned. An example of deep-level tasks is the animacy judgement task in which subjects need to decide whether a word is a living or non-living object. The case judgement task is an example of a surface-level task where subjects need to decide whether a word is printed in uppercase or lowercase (Galli, 2014). The levels-of-processing effect was mostly examined at the word level and we suggest two possible explanations for this. Firstly, the practical constraints of the MRI scanner result in the use of very basic learning tasks. Secondly, Craik and Lockhart's (1972) levels-of-processing framework was extensively investigated in experimental research at the word level on memory (Gallo, Meadow, Johnson, & Foster, 2008; Sporer, 1991; Weinstein, Bugg, & Roediger, 2008). In addition, this line of experimental research provided clear and convergent outcomes; namely, that deep processing strategies lead to better recall performance than surface processing strategies (Richardson, 2015). These robust findings at the behavioral level serve as a good start to setting up neuroscientific research, because clear hypotheses can be tested (Mayer, 1998). We can conclude that fMRI research is no bridge too far when it is used to gain more insight into processing strategies at the word level. However, we want to emphasize that a great variety of encoding tasks is used in this line of research, making it hard to compare studies (Catrysse et al., 2019). The review of Galli (2014) indicated that it is hard to precisely distinguish between deep and surface encoding tasks. Galli (2014) suggested that this is one of the main reasons why neuroscientific research is offering mixed evidence on whether the distinction between deep and surface processing strategies is qualitative or quantitative in nature.

CHALLENGES

As described in the above section, first and second pass reading times are often used as measures in eye movement research but can be an indication of different cognitive processes (Ariasi & Mason, 2011; Holmqvist et al., 2011; Hyönä et al., 2003). With regard to fMRI research, the brain is a busy place with all regions working at the same time (Varma et al., 2008). For both types of psychophysiological measures (eye tracking and fMRI), it is thus not so straightforward to interpret these micro-measures of learning. Therefore, a first challenge that is discussed is the interpretation of these micro-measures. Another point of consideration when using psychophysiological measures is taking the lab setting into account, by which one is limited in using a great variety of learning tasks. The ecological validity of learning tasks is discussed as a second challenge. A last challenge that is described is how to handle the more complex datasets resulting from using psychophysiological measures.

Interpretation of Micro-measures

Eye movement registrations and brain imaging methods are able to capture unconscious processing activities that a student would not be able to report on. Therefore, it is hard for subjects to consciously manipulate their responses (Dimoka et al., 2012). As a consequence, the micro-measures are often described as a more objective measure of processing activities. However, we believe that one of the main challenges in eye movement and brain imaging research is to interpret these micro-measures of processing and we therefore argue that these measures are often not as objective as they are described. For example, eye tracking studies have shown that second pass reading times can be an indication of different cognitive processes, such as comprehension monitoring, deeper processing, difficulty with text passages, multiple use of processing strategies, deeper processing in combination with interest, among others (Ariasi, Hyönä, Kaakinen, & Mason, 2017; Catrysse et al., 2018, Catrysse, Gijbels, Donche et al., 2018; Hyönä & Lorch, 2004; Hyönä et al., 2002, 2003). With regard to brain imaging methods, a point of consideration is that the brain is a busy place, with all regions working at all times. To obtain task-relevant signals, participants need to perform the task of interest and the control task during many trials (Varma et al., 2008). Often cognitive subtraction is than used in which the experimental task is compared with the control task to infer which brain regions are specialized for a particular cognitive component (Ward, 2010). In addition, the collection of behavioral data is a necessary step in most brain imaging studies (De Smedt, 2014; Ward, 2010). In memory research, the subsequent memory paradigm is often used (Cabeza & Nyberg, 2000), in which participants are presented with items that they need to remember and the brain imaging data is later analyzed as a function of whether the items were remembered or forgotten during a memory test (Gazzaniga, Ivry, & Mangun, 2014). Whether a word or word pair will be remembered or not not only depends on the processing strategies that were used but also on the way the memory is probed (Craik & Lockhart, 1972; Galli, 2014; Tulving & Thompson, 1973). In addition, when processing strategies are examined at the text level, recall measures have a stronger relationship with surface processing, such as memorizing the text, than with deep processing, such as trying to understand the underlying meaning of the text (Dinsmore & Alexander, 2012).

Multi-method designs are therefore a crucial step to further interpret these micro-measures (van Gog & Jarodzka, 2013; Veenman, 2005). In eye movement research, self-report measures are often used to further interpret the longer fixation durations (Catrysse et al., 2018; van Gog & Jarodzka, 2013). In fMRI research, memory tests are mostly used in order to distinguish between successful and unsuccessful processing and learning (Cabeza & Nyberg, 2000). These psychophysiological measures cannot be used as stand-alone measures, and one should be careful with the interpretation of longer fixation durations or higher activity in certain brain areas as it can be related to different cognitive processes.

Ecological Validity of Learning Tasks

A consequence of using eye movement and brain imaging methods is that this research is almost always conducted in a lab setting. With regard to eye movement research, screen-based eye-trackers or eye-tracking glasses can be used. A limitation of using eye movements with a screen-based eye tracker (i.e., the eye tracking equipment is integrated into the computer screen) to examine students' processing strategies, is that one is only able to investigate students' mental or covert processing strategies. Overt processing strategies produce physical records, such as text notes, summaries, mind maps, while covert strategies do not produce this kind of record and refer to internal mental learning processes (Kardash & Amlund, 1991; Merchie & Van Keer, 2014). Eye movement glasses are worn as normal glasses and, thus, allow the students to freely inspect and interact with all kinds of learning materials. However, there is a downside on using eye movement glasses because the data is more complex to analyze than with screen-based eye trackers, and the eye movement glasses have a lower sampling frequency than screen-based eye trackers (Holmqvist & Andersson, 2017). The computer overlays the gaze data onto the scene video and shows with a marker where the participant is looking. Even if there is a data file, the coordinates of the data refer to the positions in the video and not to positions in the text. Each dataset for each participant will thus be different, which makes it less straightforward to analyze the data afterwards (Holmqvist & Andersson, 2017). Another important aspect of eye movement research is the eye tracker calibration. During the calibration procedure, a dot is moving on the screen and the participant needs to follow the dot with his/her eyes. After this procedure, it can be verified whether the eye gaze can be recorded on different points on the screen. It is important that the eye-tracker be calibrated before and during longer reading processes in order to assure good data quality (Holmqvist et al., 2011). As a consequence, either shorter learning tasks are used or longer learning tasks are used but need to be interrupted for a calibration procedure. Therefore, questions can be raised on the ecological validity of the learning tasks used in eye movement research.

Concerning brain imaging methods, even greater issues arise with regard to the ecological validity of learning tasks. A typical characteristic of fMRI research is the highly controlled environment (Varma et al., 2008). The magnetic resonance imaging (MRI) scanner is a very noisy environment in which subjects have to lie still and are not allowed to move (De Smedt, 2014; Huettel et al., 2014). During an experiment, participants see stimuli projected on a small hanging mirror and are mostly asked to respond by pressing buttons (Varma et al., 2008). These practical constraints result in the use of restricted paradigms in which very elementary tasks, such as learning words, are used (De Smedt, 2014; Howard-Jones, Ott, van Leeuwen, & De Smedt, 2014; Willems, 2015). Thus, fMRI research is limited on what it can tell us about the contextual aspects that are crucial for learning (Varma et al., 2008). Some studies have already moved into studying differences in reading strategies at the text level (Moss & Schunn, 2015; Moss, Schunn, Schneider, & McNamara, 2013; Moss, Schunn, Schneider, McNamara, & Vanlehn, 2011). However, in our opinion fMRI may be a bridge too far at the moment to examine differences in processing strategies at the text level. We believe this first because, in the studies of Moss and colleagues, participants were not able to look back at the short paragraphs (Moss & Schunn, 2015; Moss et al., 2011, 2013). Short paragraphs of two to four sentences were presented only at one point in time. However, there is a vast tradition of eye movement research that shows that look back behavior is a crucial aspect for strategic and deeper cognitive processing when processing words, sentences and texts (Ariasi et al., 2017; Holmqvist et al., 2011; Jarodzka & Brand-Gruwel, 2017; Penttinen et al., 2013; Rayner, 2009). Especially in text comprehension, it is not only crucial to look back within words or sentences but also within and between paragraphs (Hyönä et al., 2003; Jarodzka & Brand-Gruwel, 2017). However, this is not (yet) possible in fMRI research. A second reason why we believe it is a bridge too far, is that we first need to gain more insight into how processing strategies are reflected in behavioral measures before we move to neuroscientific research. Processing strategies were mostly measured with self-report questionnaires at a more general level by which the learning task was often neglected (Dinsmore & Alexander, 2012; Fryer, 2017; Vermunt & Donche, 2017). It is only more recently that think-aloud protocols (Dinsmore & Alexander, 2016; Dinsmore & Zoellner, 2018) and eye movement registration have been used to investigate differences in processing strategies during text learning (Catrysse et al., 2016, 2018; Catrysse et al., 2018). We agree with the suggestion of Varma et al. (2008) that, in order to move beyond the practical constraints of the MRI scanner, more contextual rich learning tasks could be given outside the scanner. However, in our opinion, fMRI will become an online outcome measure and not an online learning process measure. If students get more complex tasks outside the scanner and are then scanned during memory tests as suggested by Varma et al. (2008), it is not a pure online measure that captures learning during the learning process.

Analysis of Complex Data

A characteristic of psychophysiological measures, such as eye movement registration and brain imaging, is that these techniques sample information with a high temporal precision (Holmqvist & Andersson, 2017; Huettel et al., 2014). This results in huge datasets per subject in comparison with the more traditional methods used in educational sciences. This calls for using other analytical techniques in order to take the complexity of the data into account. With regard to analyzing the eye movement data on learning from a text, we want to emphasize the strengths of applying mixed effects models. Although this analytical technique was described in good practices by different researchers in 2008 (Baayen, 2008; Baayen, Davidson, & Bates, 2008; Quené & van Den Bergh, 2008), it is only very recently that eye tracking researchers have adapted this analysis technique to examine eye movement data on reading/learning from texts (Ariasi et al., 2017; Catrysse et al., 2018; Catrysse et al., 2018). Mixed effects models offer several advantages in comparison with other techniques, such as repeated measures ANOVA (Baayen, 2008; Baayen et al., 2008; Quené & van Den Bergh, 2008). A first advantage is that mixed effects models offer more statistical power by conducting analysis on the sentence level instead of on the subject level. Furthermore, mixed effects models have a lower risk of capitalization on chance, i.e., type I error (Quené & van Den Bergh, 2008). Other advantages of mixed effects models include, among others, better methods for treating continuous responses and better methods for modeling heteroscedasticity and non-spherical error variance. In addition, by treating subjects, sentences and texts (if applicable) as crossed items, results can be jointly generalized over similar subjects, sentences and texts (Baayen, 2008; Quené & van Den Bergh, 2008). Subjects, sentences and texts are sampled from a larger population and it is thus important to take this into account in the analysis. Thus, we highly recommend applying mixed effects models for the analysis of eye movement data.

DISCUSSION AND PATHS FOR FUTURE RESEARCH

Eye movements, and more specifically second pass fixation durations, reflect partly what students report on their processing strategies. Deeper cognitive processing, as referred to in eye movement research (Ariasi & Mason, 2011; Holmqvist & Andersson, 2017; Penttinen et al., 2013), is not the same as deep processing, as defined by theoretical models on students' processing strategies (Dinsmore, 2017; Vermunt & Donche, 2017). Deep processing, as defined in theoretical models on processing strategies, refers to the intention to understand what the author wants to say in the text, to engage in meaningful learning, to relate the content of the text to a wider context and prior knowledge, and to focus on the main themes and key information in the text (Dinsmore, 2017; Vermunt & Donche, 2017). The study of Catrysse et al. (2016) showed that when students received reproduction-oriented questions that they processed details in the text more thoroughly than students who received questions aimed at deeper processing. This study showed that longer second pass fixation durations can also be related to surface processing strategies and, thus, do not always reflect the deep processing strategies as referred to in theoretical models on processing strategies. Other research provided evidence that longer second pass fixation durations do not solely reflect deep processing strategies. Longer second pass fixation durations are an indication of the multiple use of processing strategies, namely, combining both surface and deep processing strategies (Catrysse et al., 2018), and can be a reflection of deeper processing strategies only in combination with a high topic interest for key sentences (Catrysse et al., 2018). These findings are shown in Figure 19.1 and propose a framework for future research with psychophysiological measures. The most central circle represents the focus of attention. The second dotted circle represents task-specific learner and contextual characteristics, such as students' interest for a learning task, their processing strategies used during a learning task and the assessment demands for a learning task, among others. The interplay of these characteristics affects the focus of attention as measured with eye tracking. The outer circle represents more general learner and contextual characteristics such as the general disposition towards processing strategies. Both circles interact with each other and affect the focus of attention. Therefore, the inner circles are represented with dotted lines, because all these characteristics interact and may affect the focus of attention. The findings described in this chapter call for two important and related actions for future research: (1) students' processing strategies is a complex and multidimensional construct and should be measured in that way, and (2) psychophysiological measures need to be applied in multi-method designs. Figure 19.1 can thus be compared with a bull's eye. In order to measure students' processing strategies more accurately, the complexity and multidimensionality of processing strategies need to be taken into account for multi-method designs. We further elaborate on these two points below.

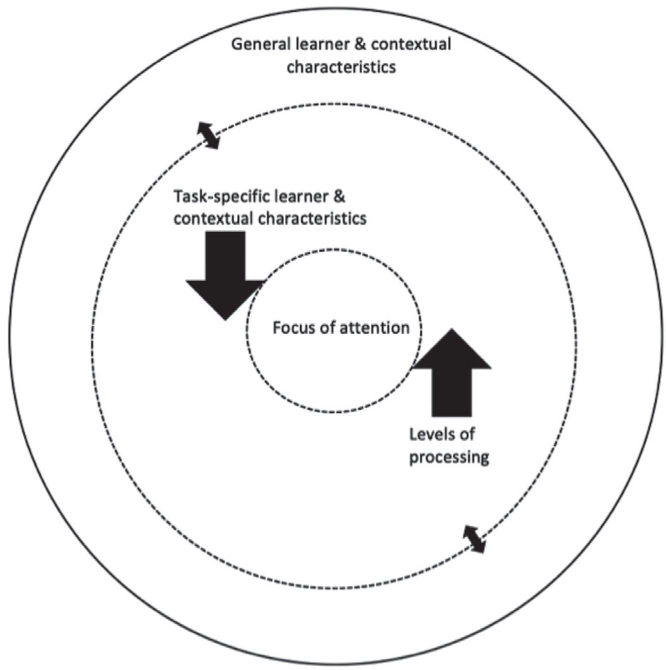

Figure 19.1 Eye Movements and Students' Processing Strategies

Based on the research discussed in this chapter, we want to stress the importance of adapting multi-method designs in order to grasp the full complexity of students' processing strategies and to avoid relying on one single method or instrument. Processing strategies and many learning processes are complex and multidimensional in nature (Alexander, 2017) and, therefore, it is impossible to capture all aspects of processing strategies with one single method. More specifically, research discussed in this chapter demonstrated the added value of applying multi-method designs in order to interpret data from psychophysiological measures. We thus want to stress the importance of combining these measures in order to understand the underlying reasons for processing behavior. By combining different methods, the power of each method is taken to obtain a comprehensive picture and deep insight into students' processing strategies (Schellings, 2011; Schellings & van Hout-Wolters, 2011). We hereby also want to emphasize that no instrument has a greater value than another; however, it is the combination of methods that results in the greatest strength.

Self-report measures such as verbal reports are mostly used in combination with eye movement data (van Gog & Jarodzka, 2013). In the discussed research, the multiple use and the nature of processing strategies was added as a predictor for explaining differences in eye movements. This research showed that both general self-report questionnaires and cued retrospective think-aloud protocols allowed an explanation of the differences in students' eye movements and their learning process. Moreover, a recent review of Dinsmore (2017) indicated that how well a strategy is used and how appropriate the chosen strategy is, are better predictors of learning outcomes than the measures that are mostly used. It would be interesting for future research to see how these aspects of students' processing strategies can explain the differences in eye movements and to verify whether these better predictors for learning outcomes are also good predictors to explain differences in the micro-processes of learning.

In eye movement studies, mostly first pass and second pass duration measures are used to analyze eye movement data (Ariasi et al., 2017; Catrysse et al., 2018; Hyönä et al., 2003; Kaakinen & Hyönä, 2007; Yeari et al., 2016). However, we are convinced that measures other than duration measures would be interesting to examine as well. As indicated in the work of Holmqvist and Andersson (2017), common analyses for reading texts and textbooks are the distribution of fixation times in areas of interest, sequence orders of areas of interest and transitions between areas of interest. Former self-report research has shown that deep processing not only refers to deeper processing of the key information in a text but also to integrating information across the text (Dinsmore & Alexander, 2016; Fox, 2009; Pressley & Afflerbach, 1995). Therefore, analyzing transition matrices would be a promising avenue to further investigate the relation between processing strategies and eye movements. Transitions are movements between areas of interest and are counted for pairs of areas of interest (Holmqvist & Andersson, 2017), for instance the number of transitions from a key sentence to another sentence. Whether key sentences are used as anchor points to process the rest of the text or not could be analyzed. This kind of analysis could clarify whether typically deep processors use key sentences as anchor points and whether, typically, surface processors use detailed sentences as anchor points in order to build up their mental representation of the text. Therefore, we suggest that future research should look further into this kind of analysis as well and go beyond solely analyzing eye movement duration measures.

For future research it would be interesting to further explore the multidimensional nature of students' processing strategies. As shown in Figure 19.1, levels of processing interact with task-specific learner and contextual characteristics. Students' processing strategies are measured in a more dynamic way with psychophysiological measures, but the other learner characteristics, such as for example interest, are up to now mostly measured in a rather static way (Catrysse et al., 2018). Constructs such as students' interest, however, are in fact clearly dynamic in nature and are expected to fluctuate during the learning process (D'Mello, Lehman, Pekrun, & Graesser, 2014). It is assumed that this dynamic response of the reader has an impact on how attentional resources are allocated during reading (Kaakinen, Ballenghein, Tissier, & Baccino, 2018; Kaakinen & Hyönä, 2014). Future research could further explore how task-specific learner characteristics, measured in a dynamic way with psychophysiological measures, interact with processing strategies while reading and/or learning. By doing so, research can shed light on the multidimensional and dynamic nature of processing strategies and its influencing characteristics.

REFERENCES

Alexander, P. A. (1997). Mapping the multidimensional nature of domain learning: The interplay of cognitive, motivational, and strategic forces. In M. L. Maehr & P. R. Pintrich (Eds.), *Advances in motivation and achievement* (pp. 213–250). Greenwich, CT: JAI Press.

Alexander, P. A. (2017). Issues of constructs, contexts, and continuity: Commentary on learning in higher education. *Educational Psychology Review*, *29*, 345–351. doi:10.1007/s10648-017-9409-3

Alexander, P. A., & Jetton, T. L. (1996). The role of importance and interest in the processing of text. *Educational Psychology Review*, *8*(1), 89–121. doi:10.1007/BF01761832
Ariasi, N., Hyönä, J., Kaakinen, J. K., & Mason, L. (2017). An eye-movement analysis of the refutation effect in reading science text. *Journal of Computer Assisted Learning*. doi:10.1111/jcal.12151
Ariasi, N., & Mason, L. (2011). Uncovering the effect of text structure in learning from a science text: An eye-tracking study. *Instructional Science*, *39*(5), 581–601. doi:10.1007/s11251-010-9142-5
Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics using R*. Cambridge, UK: Cambridge University Press.
Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language*, *59*(4), 390–412. doi:10.1016/j.jml.2007.12.005
Baeten, M., Kyndt, E., Struyven, K., & Dochy, F. (2010). Using student-centred learning environments to stimulate deep approaches to learning: Factors encouraging or discouraging their effectiveness. *Educational Research Review*, *5*(3), 243–260. doi:10.1016/J.Edurev.2010.06.001
Biggs, J. (1987). *Student approaches to learning and studying. Research monograph*. Melbourne: Australian Council for Educational Research.
Biggs, J. (1993). What do inventories of students' learning processes really measure? A theoretical review and clarification. *British Journal of Educational Psychology*, *63*(1), 3–19. doi:10.1111/j.2044-8279.1993.tb01038.x
Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher*, *26*(8), 4–16. doi:10.3102/0013189X026008004
Cabeza, R., & Nyberg, L. (2000). Imaging cognition II: An empirical review of 275 PET and fMRI studies. *Journal of Cognitive Neuroscience*, *12*(1), 1–47. doi:10.1162/08989290051137585
Catrysse, L., Gijbels, D., & Donche, V. (2019). A systematic review on the conceptualization and operationalization of students' levels of processing in fMRI studies. *Mind, Brain, and Education*. doi:10.1111/mbe.12199
Catrysse, L., Gijbels, D., & Donche, V. (2018). It is not only about the depth of processing: what if eye am not interested in the text?. *Learning and Instruction*, (58), 284–294. doi:10.1016/j.learninstruc.2018.07.009
Catrysse, L., Gijbels, D., Donche, V., De Maeyer, S., Lesterhuis, M., & Van Den Bossche, P. (2018). How are learning strategies reflected in the eyes? Combining results from self-reports and eye-tracking. *British Journal of Educational Psychology*, *88*(1), 118–137. doi:10.1111/bjep.12181
Catrysse, L., Gijbels, D., Donche, V., De Maeyer, S., Van Den Bossche, P., & Gommers, L. (2016). Mapping processing strategies in learning from expository text: An exploratory eye tracking study followed by a cued recall. *Frontline Learning Research*, *4*(1), 1–16. doi:10.14786/flr.v4i1.192
Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior*, *11*, 671–684. doi:10.1016/S0022-5371(72)80001-X
D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction*, *29*, 153–170.
De Smedt, B. (2014). Advances in the use of neuroscience methods in research on learning and instruction. *Frontline Learning Research*, *6*, 7–14. doi:10.14786/flr.v2i4.115
Dimoka, A., Banker, R. D., Benbasat, I., Davis, F. D., Dennis, A. R., Gefen, D., … Weber, B. (2012). On the use of neurophysiological tools in IS research: Developing a research agenda for neuroIS. *Mis Quarterly*, *36*(3), 679–702.
Dinsmore, D. L., & Hattan, C. (this volume). Levels of strategies and strategic processing. In D. L. Dinsmore, L. K. Fryer, & M. M. Parkinson (Eds.), *Handbook of strategies and strategic processing: Conceptualization, measurement, and analysis*. New York: Routledge.
Dinsmore, D. L. (2017). Toward a dynamic, multidimensional research framework for strategic processing. *Educational Psychology Review*. doi:10.1007/s10648-017-9407-5
Dinsmore, D. L., & Alexander, P. A. (2012). A critical discussion of deep and surface processing: What it means, how it is measured, the role of context, and model specification. *Educational Psychology Review*, *24*(4), 499–567. doi:10.1007/s10648-012-9198-7
Dinsmore, D. L., & Alexander, P. A. (2016). A multidimensional investigation of deep-level and surface-level processing. *Journal of Experimental Education*, *84*, 213–244. doi:10.1080/00220973.2014.979126
Dinsmore, D. L., & Zoellner, B. P. (2018). The relation between cognitive and metacognitive strategic processing during a science simulation. *British Journal of Educational Psychology*, *88*(1), 95–117. doi:10.1111/bjep.12177
Donche, V., & Van Petegem, P. (2009). The development of learning patterns of student teachers: A cross-sectional and longitudinal study. *Higher Education*, *57*(4), 463–475. doi:10.1007/s10734-008-9156-y
Entwistle, N., & Waterston, S. (1988). Approaches to studying and levels of processing in university students. *British Journal of Educational Psychology*, *58*(3), 258–265. doi:10.1111/j.2044-8279.1988.tb00901.x
Fox, E. (2009). The role of reader characteristics in processing and learning from informational text. *Review of Educational Research*, *79*(1), 197–261. doi:10.3102/0034654308324654

Fryer, L. K. (2017). Building bridges: Seeking structure and direction for higher education motivated learning strategy models. *Educational Psychology Review*, *29*(2), 325–344. doi:10.1007/s10648-017-9405-7

Galli, G. (2014). What makes deeply encoded items memorable? Insights into the levels of processing framework from neuroimaging and neuromodulation. *Front Psychiatry*, *5*, 1–8. doi:10.3389/fpsyt.2014.00061

Gallo, D. A., Meadow, N. G., Johnson, E. L., & Foster, K. T. (2008). Deep levels of processing elicit a distinctiveness heuristic: Evidence from the criterial recollection task. *Journal of Memory and Language*, *58*(4), 1095–1111. doi:10.1016/j.jml.2007.12.001

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (2014). *Cognitive neuroscience. The biology of the mind* (4th ed.). New York: W.W. Norton & Company.

Gielen, S., Dochy, F., & Dierick, S. (2003). Evaluating the consequential validity of new modes of assessment: The influence of assessment on learning, including pre-, post- and true assessment effects. In M. Segers, F. Dochy, & E. Cascallar (Eds.), *Optimising new modes of assessment: In search of qualities and standards* (pp. 37–54). The Netherlands: Kluwer Academic Publishers.

Holmqvist, K., & Andersson, R. (2017). *Eye tracking: A comprehensive guide to methods, paradigms and measures*. Lund, Sweden: Lund Eye-Tracking Research Institute.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., & van de Weijer, J. (2011). *Eye tracking: A comprehensive guide to methods and measures*. Oxford: Oxford University Press.

Howard-Jones, P. A., Ott, M., van Leeuwen, T., & De Smedt, B. (2014). The potential relevance of cognitive neuroscience for the development and use of technology-enhanced learning. *Learning, Media and Technology*, *40*(2), 131–151. doi:10.1080/17439884.2014.919321

Huettel, S. A., Song, A. W., & McCarthy, G. (2014). *Functional magnetic resonance imaging* (3rd ed.). Sunderland, Massachusetts U.S.A: Sinauer Associates, Inc. Publishers.

Hyönä, J., & Lorch, R. F. (2004). Effects of topic headings on text processing: Evidence from adult readers' eye fixation patterns. *Learning and Instruction*, *14*(2), 131–152. doi:10.1016/j.learninstruc.2004.01.001

Hyönä, J., Lorch, R. F., & Kaakinen, J. K. (2002). Individual differences in reading to summarize expository text: Evidence from eye fixation patterns. *Journal of Educational Psychology*, *94*(1), 44–55. doi:10.1037//0022-0663.94.1.44

Hyönä, J., Lorch, R. F., & Rinck, M. (2003). Eye movement measures to study global text processing. In J. Hyönä, R. Radach, & H. Deubel (Eds.), *The mind's eye: Cognitive and applied aspects of eye movement research* (pp. 313–334). Amsterdam: Elsevier Science.

Jarodzka, H., & Brand-Gruwel, S. (2017). Tracking the reading eye: Towards a model of real-world reading. *Journal of Computer Assisted Learning*, *33*(3), 193–201. doi:10.1111/jcal.12189

Kaakinen, J. K., Ballenghein, U., Tissier, G., & Baccino, T. (2018). Fluctuation in cognitive engagement during reading: evidence from concurrent recordings of postural and eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. doi:10.1037/xlm0000539

Kaakinen, J. K., & Hyönä, J. (2005). Perspective effects on expository text comprehension: Evidence from think-aloud protocols, eyetracking, and recall. *Discourse processes*, *40*(3), 239–257. doi:10.1207/s15326950dp4003_4

Kaakinen, J. K., & Hyönä, J. (2007). Perspective effects in repeated reading: An eye movement study. *Memory & Cognition*, *35*(6), 1323–1336. doi:10.3758/BF03193604

Kaakinen, J. K., & Hyönä, J. (2008). Perspective-driven text comprehension. *Applied Cognitive Psychology*, *22*, 319–334. doi:10.1002/acp.1412

Kaakinen, J. K., & Hyönä, J. (2014). Task relevance induces momentary changes in the functional visual field during reading. *Psychological Science*, *25*, 626–632.

Kaakinen, J. K., Hyönä, J., & Keenan, J. M. (2002). Perspective effects on online text processing. *Discourse processes*, *33*(2), 159–173. doi:10.1207/S15326950DP3302_03

Kardash, C. M., & Amlund, J. T. (1991). Self-reported learning strategies and learning from expository text. *Contemporary Educational Psychology*, *16*, 117–138. doi:10.1016/0361-476X(91)90032-G

Kendeou, P., & Trevors, G. (2012). Quality learning from texts we read. What does it take? In J. R. Kirby & M. J. Lawson (Eds.), *Enhancing the quality of learning. Dispositions, instruction, and learning processes* (pp. 251–314). New York: Cambridge university press.

Kintsch, W. (1998). *Comprehension. A paradigm for cognition*. United Kingdom: Cambridge University Press.

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production.. *Psychological Review*, *85*(5), 363–394. doi:10.1037/0033-295X.85.5.363

Kirby, J. R., Cain, K., & White, B. (2012). Deeper learning in reading comprehension. In J. R. Kirby & M. J. Lawson (Eds.), *Enhancing the quality of learning. Dispositions, instruction, and learning processes* (pp. 315–338). New York: Cambridge University Press.

Lonka, K., Lindblom-Ylänne, S., & Maury, S. (1994). The effect of study strategies on learning from text. *Learning and Instruction*, *4*, 253–271. doi:10.1016/0959-4752(94)90026-4
Lonka, K., Olkinuora, E., & Mäkinen, J. (2004). Aspects and prospects of measuring studying and learning in higher education. *Educational Psychology Review*, *16*(4), 301–323. doi:10.1007/s10648–004–0002–1
Marton, F., & Säljö, R. (1976). On qualitative differences in learning: I - Outcome and process. *British Journal of Educational Psychology*, *46*(1), 4–11. doi:10.1111/j.2044-8279.1976.tb02980.x
Mason, L. (2009). Bridging neuroscience and education: A two-way path is possible. *Cortex*, *45*(4), 548–549. doi:10.1016/j.cortex.2008.06.003
Mayer, R. E. (1998). Does the brain have a place in educational psychology. *Educational Psychology Review*, *10*(4), 389–396. doi:10.1023/A:1022837300988
Merchie, E., & Van Keer, H. (2014). Using on-line and off-line measures to explore fifth and sixth graders' text-learning strategies and schematizing skills. *Learning and Individual Differences*, *32*, 193–203. doi:10.1016/j.lindif.2014.03.012
Moss, J., & Schunn, C. D. (2015). Comprehension through explanation as the interaction of the brain's coherence and cognitive control networks. *Frontiers in Human Neuroscience*, *9*, 562. doi:10.3389/fnhum.2015.00562
Moss, J., Schunn, C. D., Schneider, W., & McNamara, D. S. (2013). The nature of mind wandering during reading varies with the cognitive control demands of the reading strategy. *Brain Research*, *1539*, 48–60. doi:10.1016/j.brainres.2013.09.047
Moss, J., Schunn, C. D., Schneider, W., McNamara, D. S., & Vanlehn, K. (2011). The neural correlates of strategic reading comprehension: Cognitive control and discourse comprehension. *Neuroimage*, *58*(2), 675–686. doi:10.1016/j.neuroimage.2011.06.034
Penttinen, M., Anto, E., & Mikkilä-Erdmann, M. (2013). Conceptual change, text comprehension and eye movements during reading. *Research in Science Education*, *43*(4), 1407–1434. doi:10.1007/s11165-012-9313-2
Pressley, M., & Afflerbach, P. (1995). *Verbal protocols of reading: The nature of construcitvely responsive reading*. Hillsdale: Erlbaum.
Quené, H., & van Den Bergh, H. (2008). Examples of mixed-effects modeling with cross random effects and with binomial data. *Journal of Memory and Language*, *59*(4), 413–425. doi:10.1016/j.jml.2008.02.002
Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Q J Exp Psychol*, *62*(8), 1457–1506. doi:10.1080/17470210902816461
Richardson, J. T. E. (2015). Approaches to learning or levels of processing: What did Marton and Säljö (1976a) really say? The legacy of the work of the Göteborg group in the 1970s. *Interchange*, *46*, 239–269. doi:10.1007/s10780-015-9251-9
Schellings, G. L. M. (2011). Applying learning strategy questionnaires: problems and possibilities. *Metacognition and Learning*, *6*(2), 91–109. doi:10.1007/s11409-011-9069-5
Schellings, G. L. M., & van Hout-Wolters, B. (2011). Measuring strategy use with self-report instruments: Theoretical and empirical considerations. *Metacognition and Learning*, *6*, 83–90. doi:10.1007/s11409-011-9081-9
Schiefele, U. (1996). Topic interest, text representation, and quality of experience. *Contemporary Educational Psychology*, *21*, 3–18. doi:0361-476X/96
Schiefele, U. (1999). Interest and learning from text. *Scientific Studies of Reading*, *3*(3), 257–279. doi:10.1207/s1532799xssr0303_4
Schiefele, U. (2012). Interests and learning. In N. M. Seel (Ed.), *Encyclopedia of the sciences of learning* (pp. 1623–1626). New York: Springer.
Schiefele, U., & Krapp, A. (1996). Topic interest and free recall of expository text. *Learning and Individual Differences*, *8*(2), 141–160. doi:10.1016/S1041-6080(96)90030-8
Segers, M., Nijhuis, J., & Gijselaers, W. (2006). Redesigning a learning and assessment environment: The influence on students' perceptions of assessment demands and their learning strategies. *Studies in Educational Evaluation*, *32*, 223–242. doi:10.1016/j.stueduc.2006.08.004
Sporer, S. L. (1991). Deep - Deeper - Deepest? Encoding strategies and the recognition of human faces. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(2), 323–333. doi:10.1037/0278-7393.17.2.323
Tulving, E., & Thompson, D. (1973). Encoding specificity and retrieval processes in episodic memory. *Pyschological Review*, *80*, 352–373. doi:10.1037/h0020071
van Dijk, T. A., & Kintsch, W. (1983). *Strategies for discourse comprehension*. New York: Academic Press.
van Gog, T., & Jarodzka, H. (2013). Eye tracking as a tool to study and enhance cognitive and metacognitve processes in computer-based learning environments. In R. Azevedo & V. Aleven (Eds.), *International handbook of metacognition and learning technologies* (pp. 143–156). New York: Springer.
Vanthournout, G., Coertjens, L., Gijbels, D., Donche, V., & Van Petegem, P. (2013). Assessing students' development in learning approaches according to initial learning profiles: A person-oriented perspective. *Studies in Educational Evaluation*, *39*(1), 33–40. doi:10.1016/j.stueduc.2012.08.002

Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educational Researcher*, *37*(3), 140–152. doi:10.3102/0013189x08317687
Veenman, M. V. J. (2005). The assessment of metacognitive skills: What can be learned from multi-method designs?. In C. Artett & B. Moschner (Eds.), *Lernstrategien und metakognition. Implikationen für forschung und praxis* (pp. 77–99). Münster: Waxmann.
Vermunt, J. D. (this volume). Surveys and retrospective self-reports to measure strategies and strategic processing. In D. L. Dinsmore, L. K. Fryer, & M. M. Parkinson (Eds.), *Handbook of strategies and strategic processing: Conceptualization, measurement, and analysis*. New York: Routledge.
Vermunt, J. D. (2005). Relations between student learning patterns and personal and contextual factors and academic performance. *Higher Education*, *49*(3), 205–234. doi:10.1007/S10734-004-6664-2
Vermunt, J. D., & Donche, V. (2017). A learning patterns perspective on student learning in higher education: State of the art and moving forward. *Educational Psychology Review*, *29*(2), 269–299. doi:10.1007/s10648-017-9414-6
Ward, J. (2010). *The students' guide to cognitive neuroscience* (2nd ed.). New York: Psychology Press.
Weinstein, Y., Bugg, J. M., & Roediger, H. L. (2008). Can the survival recall advantage be explained by basic memory processes?. *Memory & Cognition*, *36*(5), 913–919. doi:10.3758/mc.36.5.913
Willems, R. M. (Ed.). (2015). *Cognitive neuroscience of natural language use*. United Kingdom: Cambridge University Press.
Yarbus, A. L. (1967). *Eye movements and vision*. New York: Plenum.
Yeari, M., Oudega, M., & van Den Broek, P. (2016). The effect of highlighting on processing and memory of central and peripheral text information: Evidence from eye movements. *Journal of Research in Reading*. doi:10.1111/1467-9817.12072
Yeari, M., van Den Broek, P., & Oudega, M. (2015). Processing and memory of central versus peripheral information as a function of reading goals: Evidence from eye-movements. *Reading and writing*, *28*, 1071–1097. doi:10.1007/s11145-015-9561-4