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Integrative Processing of Verbal and Graphical Information During Re-reading Predicts Learning from Illustrated Text: An Eye-Movement Study

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(Article begins on next page)

3 **Integrative processing of verbal and graphical**  
4 **information during re-reading predicts learning**  
5 **from illustrated text: an eye-movement study**

6 **Lucia Mason · Maria Caterina Tornatora ·**  
7 **Patrik Pluchino**

8  
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10 **Abstract** Printed or digital textbooks contain texts accompanied by various kinds of  
11 visualisation. Successful comprehension of these materials requires integrating verbal  
12 and graphical information. This study investigates the time course of processing an  
13 illustrated text through eye-tracking methodology in the school context. The aims were  
14 to identify patterns of first- and second-pass reading and to examine whether the inte-  
15egrative processing of text and picture during the less automatic and more purposeful  
16 second-pass reading predicts learning, after controlling for reading comprehension, prior  
17 knowledge, and self-concept. Forty-three 7th graders read an illustrated science text  
18 while their eye movements were recorded. A cluster analysis revealed two processing  
19 patterns during the first-pass reading, which differed for the time spent on the main  
20 concepts in the text and picture. During re-reading, two patterns of stronger and weaker  
21 integrative processing emerged. Integration of verbal and graphical information was  
22 revealed by the frequency of second-pass transitions from text to picture and from picture  
23 to text, and the duration of picture re-inspecting while re-reading text information (look-  
24 from text to picture) and re-reading text information while re-inspecting the visualised  
25 information (look-from picture to text). A series of hierarchical regression analyses  
26 indicated that only the patterns of integrative processing during the second-pass reading  
27 uniquely predict verbal and graphical recalls, and the transfer of knowledge. The study

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28 provides evidence that the delayed processing which integrates text and graphics con-  
 29 tributes to text retention and the application of newly learned knowledge, over and above  
 30 individual characteristics. The educational significance is outlined.

31  
 32 **Keywords** Text processing · Reading comprehension · Integrative processing ·  
 33 Multimedia learning · Eye movements

## 37 Introduction

38 Reading comprehension is essential to learning new knowledge in content areas and  
 39 is sustained by various cognitive, motivational, and contextual factors (Alexander,  
 40 2012; Bråten, Ferguson, Anmarkrud, & Strømsø, 2013; Kim, Petscher, & Foorman,  
 41 2013; Taboada, Tonks, Wigfield, & Guthrie, 2009). Printed or digital textbooks and  
 42 websites accessed as information sources contain texts accompanied by various  
 43 kinds of visual displays to support learning: diagrams, graphs, photographs, charts,  
 44 maps, etc. Successful comprehension of these materials requires comprehension of  
 45 multiple external representations, which have potential benefits (Ainsworth, 2006).

46 The multimedia principle states that comprehension is better when learning from  
 47 text and pictures, rather than from text alone (Mayer, 2009). Empirical research has  
 48 documented that texts accompanied by visuals are more effective than non-illustrated  
 49 texts (e.g., Butcher, 2006; Mason, Pluchino, Tornatora, & Ariasi, 2013) regardless of  
 50 the domains of study, whether presentation formats are paper or digital, and whether  
 51 assessment is for retention or transfer of knowledge (Butcher, 2014; Eitel & Scheitel,  
 52 2014 for recent reviews). In particular, some graphical reading processes are correlated  
 53 with comprehension measures (Norman, 2012). Research has also shown that students'  
 54 metacognitive judgments reflect their belief that they learn better from texts with  
 55 diagrams than from texts alone, even when visuals are not effective (Serra & Dunlosky,  
 56 2010). Students may believe that they comprehend pictures easily as they are processed  
 57 faster than written texts (Schroeder et al., 2011). Students may also skip over relevant  
 58 visuals when interacting with a biology text which includes complex diagrams,  
 59 although they are able to engage in high-level cognitive activity when they do read the  
 60 diagrams (Cromley, Snyder-Hogan & Luciw-Dubas, 2010a, 2010b).

61 What underlies the beneficial effects of multimedia instructional materials? Through  
 62 the current study we aimed to extend previous research providing evidence that what  
 63 uniquely contributes to the successful comprehension of an illustrated science text is the  
 64 integrative processing of verbal and graphical information. This takes place during the  
 65 delayed and more purposeful re-reading of the instructional material. To this aim we  
 66 used eye-tracking methodology in the context of a lower-secondary school to trace  
 67 students' verbal and graphical information processing as revealed by multiple indices of  
 68 visual behavior while interacting with an illustrated science text.

69 Multimedia principle and comprehension of text and picture

70 Two theoretical accounts may explain the potentially beneficial effects of  
 71 multimedia materials. The first is the cognitive theory of multimedia learning

72 (Mayer, 2009, 2014). According to this theory three essential processes lead to the  
 73 comprehension of verbal and graphical information: selection, organization and  
 74 integration. The selection process leads to the extraction of relevant words from the  
 75 text and relevant elements from the picture. During the organization process the  
 76 selected material is processed further for comprehension and retention of textual and  
 77 graphical information. This process results in the construction of a verbal model and  
 78 a pictorial model. The last process implies connecting these two models with each  
 79 other and with relevant prior knowledge retrieved from long-term memory to form a  
 80 coherent mental representation.

81 The second theoretical account of the potential benefits associated with an  
 82 illustrated text is the integrated model of text and picture comprehension (Schnotz,  
 83 2014; Schnotz & Bannert, 2003). According to this model, dual coding applies to  
 84 the processing of both texts and images, and the different principles of  
 85 representation complement each other. For text comprehension, constructive  
 86 processes based on schemata with both selective and organizational functions lead  
 87 to a structured propositional representation. A mental model from a mental  
 88 representation of the text surface structure is also formed. Similar processes occur  
 89 for picture comprehension starting from the visual perception of the picture and  
 90 resulting in a mental model and a propositional representation of the content via  
 91 high-order cognitive processing. The formation of a coherent mental model of an  
 92 illustrated text relies on structural mapping processes involving the propositional  
 93 representation and the mental model, in both text and picture comprehension.

94 According to both theoretical accounts, integration processes are crucial to  
 95 learning from texts and pictures, once relevant information has been selected and  
 96 organized. It is worth noting that the integration of verbal and graphical information  
 97 may concern not only the text segments that correspond precisely to the graphical  
 98 segments, but also the non-corresponding segments. For example, when a student  
 99 reads about condensation in a text regarding the water cycle, s/he may need to look  
 100 at the depiction of evaporation to understand better the difference between the two  
 101 phenomena, or to connect different but relevant segments of the two (verbal and  
 102 graphical) representations.

103 If successful comprehension of an illustrated text implies the integration of  
 104 verbal and graphical information, it seems particularly relevant to examine when  
 105 integrative processing occurs and whether it uniquely predicts learning from text  
 106 over and above individual characteristics. In this regard, eye-movement recording is  
 107 a useful methodology to trace the time course of information processing and to  
 108 attain quantitative and objective indices of visual behavior during reading (Rayner,  
 109 Chace, Slattery & Ashby, 2006).

## 110 Processing of text and picture: evidence from eye-tracking data

111 Eye-tracking methodology has received increasing attention in research on  
 112 multimedia learning (van Gog & Scheiter, 2010; Mayer, 2010; Hyönä, 2010).  
 113 Several eye-tracking studies have contributed to unravelling aspects of university  
 114 students' text and picture processing (e.g., Eitel, Scheiter, Schüler, Nyström &  
 115 Holmqvist, 2014; Hegarty & Just, 1993; Johnson & Mayer, 2012; Stalbovs, Eitel &



116 Scheiter, 2013). However, only few investigations have focused on text and picture  
 117 processing in younger students. A pioneering study was carried out by Hannus and  
 118 Hyönä (1999) with 10-year-old students learning biology textbook materials. Eye-  
 119 fixation data showed that the readers attended only marginally the graphical  
 120 representations and their comprehension was largely driven by the text. High-ability  
 121 students, however, attended for relatively more time the pertinent segments of the  
 122 verbal and visual material (experiment 2).

123 Recently, Mason, Pluchino and Tornatora (2014) examined the effects of reading  
 124 a science text illustrated by either a labelled or an unlabelled picture in 6th graders.  
 125 It emerged that the former promotes more integrative processing of the verbal and  
 126 graphical parts of learning material, as revealed by the time spent re-inspecting the  
 127 picture while re-reading the text and vice versa. In addition, integrative processing  
 128 correlated with scores for factual knowledge and transfer of knowledge.

129 Another study focused on the role of a concrete and an abstract picture in  
 130 illustrating a science text to 11th graders. The concrete picture was a contextualized  
 131 representation of the scientific concept introduced in the text, where the concept of  
 132 an inclined plane was depicted in a mountain scenario. The abstract picture was a  
 133 decontextualized representation as the inclined plane and descending body were  
 134 depicted schematically without using a realistic scenario. It emerged that the  
 135 participants processed the verbal information more efficiently and made a greater  
 136 effort to integrate it with the pictorial information when reading the text  
 137 accompanied by an abstract, rather than a concrete illustration. Moreover, some  
 138 indices of integrative processing during the second-pass reading, as revealed by the  
 139 frequency of transitions (gaze shifts) from text to illustration and vice versa,  
 140 correlated with learning outcomes (Mason et al., 2013c).

141 A recent eye-tracking study examined the strategies used by fifth and eighth  
 142 graders when dealing with texts and pictures. It revealed that they serve different  
 143 functions associated with different processing strategies. Texts seem to be used for  
 144 coherence-oriented general processing. Pictures can act as scaffolds for initial  
 145 mental model construction and then for task-driven selective processing when  
 146 necessary to update mental models of specific items (Schnotz et al., 2014).

147 Particularly pertinent to the present investigation is the study carried out by  
 148 Mason, Tornatora and Pluchino (2014). Using multiple indices, they identified  
 149 patterns of eye movements in 4th graders who learned new knowledge from a text  
 150 and picture on the topic of air. Better learning performances were associated with  
 151 the pattern characterized by longer total fixation time on the picture, and greater  
 152 integrative processing of verbal and graphical information. It is worth noting that  
 153 the authors have distinguished indices of first- and second-pass, but they have  
 154 considered together both types of index when identifying patterns of visual behavior  
 155 during reading. Therefore, they did not indicate which processing—immediate,  
 156 delayed or both—was essential to reading outcomes.

157 The current study

158 To add to the existing literature, this open issue was addressed in the current study,  
 159 examining the immediate and delayed effects of reading processing separately.

160 Theoretically, we took into consideration the strategy proposed by Bartholomé and  
 161 Bromme (2009) to promote the construction of an integrated coherent representation  
 162 of text and graphics. Based on the cognitive processes envisioned in the Mayer  
 163 (2009) and Schnotz and Bannert (2003) theoretical accounts, this strategy includes  
 164 three steps of text and picture processing in which the latter is conceptually guided  
 165 by the former. First, readers process the whole text to identify central concepts.  
 166 Second, readers inspect the picture using text information to direct it in order to  
 167 identify the visualizations of the central concepts of the text. This step also implies  
 168 making correspondences between the verbal and graphical representations, shifting  
 169 from one to the other. Third, readers continue relating the two types of  
 170 representation and then focus on the verbal parts that are not depicted, since text  
 171 and pictures can be mapped only partially.

172 Methodologically, we found eye tracking to be a very useful technique: initial  
 173 reading or inspection can be separated from later re-processing. In this respect, the  
 174 first step of the strategy mentioned above implies initial or first-pass reading, the  
 175 second step implies initial or first-pass inspection and then re-processing or second-  
 176 pass reading and inspection of verbal and graphical information, which continues  
 177 during the third step.

178 The first pass-reading or inspecting is considered to reflect early processing. It is  
 179 the summed duration of all fixations on a target region before exiting it. The second-  
 180 pass reading or inspecting is the summed duration of fixations that return to the  
 181 target region after its first-pass reading. The second-pass reading is considered to  
 182 reflect delayed processing, which can indicate, on the one hand, the readers'  
 183 attempts to resolve comprehension difficulties during reading (Rayner, 2009) and,  
 184 on the other, a more purposeful reading behavior than the first-pass (Hyönä, Lorch  
 185 & Kaakinen, 2002; Hyönä, & Nurminen, 2006). Indices of second-pass reading can  
 186 be further categorized on the basis of their destination and origin (see below the  
 187 section on eye-movement measures). More light on the integrative processing of  
 188 verbal and graphical information, especially whether it is the only type that predicts  
 189 various forms of learning from an illustrated text, would have theoretical and  
 190 practical significance.

191 We sought therefore to contribute to understanding which processing of text and  
 192 graphics is associated with successful learning from science text in lower-secondary  
 193 school, after controlling for some important individual differences. In this respect,  
 194 we took into account that a large body of research on the comprehension of  
 195 informational text has indicated that some individual characteristics affect reading  
 196 outcomes. In this study we considered two crucial cognitive factors: reading  
 197 comprehension and prior knowledge, and one motivational factor: self-concept.

198 Reading comprehension skills, by definition, are expected to be related to  
 199 learning from text (e.g., Schellings, Aarnoutse & van Leeuwe, 2006). Skilled  
 200 readers are more likely to comprehend a text at a deeper level, that is, the situation  
 201 model level.

202 Another reader characteristic that can be easily conceived as influencing learning  
 203 from text is prior knowledge of the topic (e.g., Kendeou & van den Broek, 2007;  
 204 McNamara & Kintsch, 1996; Ozuru, Dempsey, & McNamara, 2009). Readers who

bring high relevant knowledge to the reading process are more likely to gain the deepest level of comprehension than low-knowledge readers.

Why reading comprehension and prior knowledge should be considered when investigating learning from text is fairly evident, but the measurement of self-concept may need some clarification. Self-concept is defined as a person's self-perceptions about her or his competence, which are formed through personal experiences and interpretations of one's environment (Marsh, 1990). Self-concept involves the totality of one's self-perceptions as well as the perceptions that one has in relation to specific areas or domains (Schunk & Pajares, 2005). In this study we considered the domain of science (science self-concept) since the instructional material regarded a scientific topic. We took into account reader characteristics in light of the research indicating that a domain-specific self-concept is closely related to performance and achievement in the domain, for example reading (Katzir, Lesaux, & Kim, 2009), science (Mason, Boscolo, Tornatora, & Ronconi, 2013) and maths (Marsh, Trautwein, Lüdtke, Köller, & Baumert, 2006).

No prior study, as far as we know, has examined the contribution of eye fixations of first- and second-pass reading to various forms of learning independent of cognitive and motivational characteristics.

The following research questions and hypotheses guided the study:

1. What distinct eye-movement patterns of processing of verbal and graphical information emerge when considering various indices of the immediate first-pass reading and indices of the delayed second-pass reading?
2. Do only eye-movement patterns of integrative processing of text and graphics during the second-pass reading uniquely predict learning from text after controlling for individual characteristics, such as reading comprehension, prior knowledge, and self-concept?

For research question 1, we expected that during the first encounter with the learning material distinct processing patterns would emerge differing for fixation times on the central concepts of the text and their visualizations. Specifically, we expected that a more laborious processing pattern due to comprehension difficulties during text reading or picture inspection would result in a longer first-pass fixation time on the verbal and graphical parts of the main concepts. In contrast, we also expected that during the second-pass reading distinct patterns of ocular behavior would emerge characterized by relatively less and more transitions (gaze shifts) from the verbal to the graphical representations, and vice versa, and by shorter or longer re-fixation times on the picture while re-reading the text (*look-from* text to picture fixation time) and re-fixation times on the text while re-inspecting the picture (*look-from* picture to text fixation time). *Look-from* fixation times would reflect delayed processing of verbal and graphical information. The more strategic pattern of eye movements would be characterized by longer second-pass integrative processing of text and picture. It is worth noting that transitions from one representation to the other can also occur during the first-pass. However, we expected that only the more purposeful transitions during re-processing would differentiate readers' ocular behavior during reading and inspecting.

250 Based on the available literature mentioned above, for research question 2, we  
 251 hypothesized that only the second-pass integrative patterns of verbal and graphical  
 252 information would uniquely predict reading outcomes over and above individual  
 253 characteristics. In particular, we expected the predictability of deeper learning, as  
 254 reflected in the transfer of knowledge. More than text retention or comprehension of  
 255 factual knowledge, it would require stronger integration of the two types of  
 256 information of the instructional material for constructing a high-quality mental  
 257 representation. Eye-movement patterns of integrative processing as predictors of  
 258 learning from text would emerge after controlling for cognitive and motivational  
 259 factors, that is, reading comprehension, prior knowledge, and self-concept, which  
 260 are all considered to be resources in text comprehension and learning.

## 261 Method

### 262 Participants

263 Forty-eight 7th graders were involved initially. They attended a public lower-  
 264 secondary school in a north-eastern region of Italy and participated on a voluntary  
 265 basis with parental consent. Because of poor eye calibration in 5 participants, we  
 266 considered the data of 43 students (22 females), with a mean age of 12.8 years  
 267 ( $SD = 8.3$  months). All were native-born Italians with Italian as their first language  
 268 and shared a homogeneous middle-class social background. All had normal or  
 269 corrected-to-normal vision. Participants were involved in a pre-test and immediate  
 270 post-test design.

### 271 Reading material

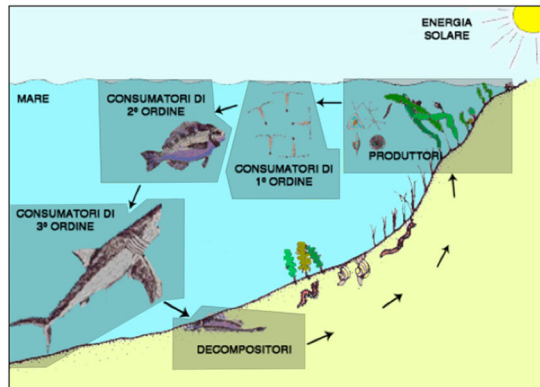
272 The illustrated text read by all participants regarded the food chain. This topic had  
 273 not been previously presented in science classes attended by the participants. The  
 274 text comprised 214 words (in Italian) and one picture (Fig. 1) and had been used in a  
 275 previous study (Mason, Pluchino, & Tornatora, 2015).

### 276 Eye-movement measures

277 Eye movements were collected using a non-invasive eye tracker (Tobii T120) in the  
 278 real school context. As an extension of existing research (Mason et al., 2013d), for  
 279 eye-movement analyses, the text was divided into sentences (areas of interest,  
 280 AOIs) taking into account whether the information provided was, or was not,  
 281 visualised in the picture. More specifically, 5 sentences were considered as  
 282 *corresponding* AOIs (i.e., areas of interest that contain the same information  
 283 depicted in the illustration) and 7 sentences were considered as *non-corresponding*  
 284 AOIs (i.e., areas of interest containing information about the food chain, but were  
 285 not depicted in the illustration). The illustration was also divided into *corresponding*  
 286 AOIs (areas that visualise text information) and *non-corresponding* AOIs (areas that  
 287 do not visualise text information).



Per il nutrimento gli organismi viventi sono collegati tra loro come tanti anelli di una catena. Tale legame si chiama catena alimentare. In qualsiasi ambiente, anche quello marino, le piante e gli animali formano varie catene alimentari. Ecco, ad esempio, come è formata una catena alimentare marina. Si comincia con i produttori: i vegetali acquatici come i vari tipi di alghe (cioè il fitoplancton). Tali organismi sfruttano l'energia solare e, attraverso la fotosintesi, trasformano sostanze di base come l'acqua e l'anidride carbonica e le sostanze minerali in zuccheri e amidi, producendo il proprio nutrimento e rilasciando anche ossigeno nell'ambiente. Di questi vegetali, detti produttori, si nutrono altri organismi, ad esempio i gamberetti e le larve (cioè lo zooplancton), che sono i consumatori di 1° ordine. Poi ci sono i consumatori di 2° ordine: le stelle marine, i ricci di mare, alcuni pesci, le tartarughe, i delfini e le balene. Esistono poi i consumatori di 3° ordine: gli uccelli marini, lo squalo e l'orca. Della catena fanno parte anche i batteri e gli altri organismi, chiamati decompositori. Questi vivono sul fondale e trasformano resti alimentari (vegetali e animali morti) in sostanze minerali, utili ai vegetali acquatici per la fotosintesi. La rottura dell'equilibrio in un anello della catena alimentare si ripercuote in tutta la catena stessa.



**Fig. 1** The instructional material with text and picture regarding the food chain. *Highlighted parts* of the text and picture are the corresponding segments of the verbal and graphical representations. Reprinted from Contemporary Educational Psychology, vol. 41, L. Mason, M. C. Tornatora, and P. Pluchino, Eye-movement modeling of text and picture integration during reading: effects on processing and learning, pp. 172–187. Copyright 2015, with permission from Elsevier

288 In the analysis of eye-movement data, we computed the frequencies of first-pass  
 289 and second-pass transitions from the corresponding and non-corresponding text  
 290 segments to the corresponding and non-corresponding picture segments and vice  
 291 versa. These measures indicate how many times a reader's gaze shifted from a given  
 292 area of the verbal representation to a given area of the graphical representation, or  
 293 from a given area of the latter to a given area of the former, during the first  
 294 encounter with the reading material and during re-reading or re-inspecting,  
 295 respectively. Transitions reflect the learner's attempts to integrate words and  
 296 pictorial elements (Johnson & Mayer, 2012).

297 We also focused on both the duration of the first- and second-pass fixation times  
 298 (in milliseconds). For the first-pass, we considered the fixation time spent on the  
 299 corresponding and non-corresponding AOIs of the text and picture summing the  
 300 duration of all fixations on either type of AOI, during the first encounter with the  
 301 learning material. For the second-pass, we considered the look-from fixation times.  
 302 *Look-from* text to picture fixation time was computed for the corresponding and  
 303 non-corresponding AOIs by summing the duration of all re-fixations that "took off"  
 304 from a segment (AOI) of the text, either corresponding or non-corresponding, and  
 305 "landed" on a corresponding segment (AOI) of the picture. Similarly, the *look-from*

306 picture to text fixation time was computed by summing the durations of all re-  
 307 fixations that “took off” from a segment of the picture, either corresponding or non-  
 308 corresponding, and “landed” on a segment of the text, either corresponding or non-  
 309 corresponding. *Look-from* measures offer an index of the extent to which a text  
 310 segment is used as an “anchor” point for processing the picture segments, or a  
 311 picture segment is used as an “anchor” point for processing text segments, which is  
 312 essential for integrative processing.

313 As mentioned in the theoretical framework, it should be noted that for  
 314 corresponding verbal and graphical segments we considered the sum of all  
 315 transitions and looks-from all visualized text AOIs to picture AOIs and vice versa.  
 316 In other words, when computing the transitions, we computed either a shift from the  
 317 text AOI “producers” to the picture AOI “producers” or a shift from the text AOI  
 318 “producers” to the picture AOI “first order consumers” and vice versa. To  
 319 exemplify, when a student reads in the text about first-order consumers s/he may  
 320 need to look at the depiction of second-order consumers to better understand the  
 321 difference between the two orders, or to connect different but relevant segments of  
 322 the two (verbal and graphical) representations. Therefore, a more global index may  
 323 better reflect the integrative processing of verbal and graphical information.

324 All eye-tracking measures were transformed logarithmically because of the great  
 325 variance in participants’ visual behavior that led to non-normal distributions.

326 Individual characteristics

327 *Reading comprehension*

328 This was measured using the Italian MT test for seventh grade (Cornoldi & Colpo,  
 329 1995). It consists in an expository text and 14 multiple-choice questions. The  
 330 reliability of this instrument has been reported in the range of .73–.82 (Cronbach’s  
 331 alpha). In the present study the reliability coefficient was =.74.

332 *Prior knowledge of the scientific topic*

333 Factual knowledge about the food chain was measured using nine questions, two  
 334 open-ended and seven multiple choice that also required a justification for the  
 335 chosen option ( $\alpha = .73$ ). Answers to the open-ended questions were awarded 0–2  
 336 points depending on their correctness and completeness. Answers to the multiple-  
 337 choice questions were scored 1–2 only when a correct justification was given. Inter-  
 338 rater reliability for coding the former and the latter, as measured by Cohen’s *k*, was  
 339 .86.

340 *Self-concept*

341 Self-concept for the domain of science was measured using six items in a 4-point  
 342 Likert-type scale ( $\alpha = .75$ ), already used in a previous study (Mason et al., 2013a).  
 343 It was taken from the Self- Description Questionnaire (Marsh, 1990). Items were

344 adapted for science (e.g. “I have always done well in science” and “I easily  
345 comprehend a text on scientific topics”).

346 Learning outcomes

347 *Verbal recall*

348 To measure text retention, participants were asked to write all that they remembered  
349 from the text, which included twenty-three information units. Recall protocols were  
350 coded according to the number of correct information units they reported. The two  
351 raters coded the recalls independently and their agreement, as measured by  
352 Cohen’s  $k$ , was .90.

353 *Graphical recall*

354 For retention assessment, participants were also asked to draw everything they could  
355 remember from the picture they observed. Graphical recalls were scored 0-2  
356 depending on their correctness and completeness. The two raters coded the drawings  
357 independently and their agreement, as measured by Cohen’s  $k$ , was .96.

358 *Factual knowledge*

359 Participants’ text-based factual knowledge about the food chain at post-test was  
360 assessed using the same nine questions asked at the pretest, and were scored in the  
361 same way by the two independent raters. Inter-rater reliability, as measured by  
362 Cohen’s  $k$ , was .93. Cronbach’s reliability coefficient for these questions was .75.

363 *Transfer of knowledge*

364 Participants’ deeper learning from text was measured using a transfer task that  
365 reveals the ability to apply the newly learned knowledge. The task included eight  
366 questions, four open questions and four multiple-choice questions that also required  
367 justification for the chosen option ( $\alpha = .77$ ). Like questions about factual  
368 knowledge, answers to the open-ended questions were awarded 0–2 points  
369 depending on their correctness and completeness. Answers to the multiple-choice  
370 questions were scored 1–2 only when a correct justification was given. Inter-rater  
371 reliability for coding the justifications was .94, as measured by Cohen’s  $k$ .

372 Procedure

373 Data collection took place in two sessions. In the first, a classroom session,  
374 participants were collectively administered the self-concept questionnaire, the pre-  
375 test questions, and the reading comprehension test. This collective part took about  
376 50–60 min. The second, an individual session, took place in a quiet room in the  
377 school. First, the eye tracker was calibrated for each participant. After calibration,  
378 the participant was instructed to read carefully and silently the illustrated text on the

379 computer screen, as s/he would be asked to answer some questions. Participants  
 380 read the material at their own pace while eye movements were recorded. They then  
 381 performed the various post-tests. This session took 45–55 min.

## 382 Results

383 Research question 1: identifying eye-movement patterns during the first  
 384 and second-pass reading

### 385 *Patterns of first-pass reading*

386 To answer research question 1, we focus first on eye movements during the  
 387 immediate and more automatic first-pass reading. Comprehension difficulties during  
 388 text reading usually imply a longer first-pass fixation time (Rayner et al., 2006). We  
 389 considered eight indices of eye movements: (1) first-pass fixation time on  
 390 corresponding text segments; (2) first-pass fixation on non-corresponding text  
 391 segments; (3) first-pass fixation time on corresponding picture segments; (4) first-  
 392 pass fixation time on non-corresponding picture segments; (5) first-pass transitions  
 393 from corresponding text segments to corresponding picture segments; (6) first-pass  
 394 transitions from non-corresponding text segments to corresponding picture  
 395 segments; (7) first-pass transitions from corresponding picture segments to  
 396 corresponding text segments; (8) first-pass transitions from non-corresponding  
 397 picture segments to corresponding text segments.

398 A cluster analysis using the Ward method was performed with the eight eye-  
 399 movement indices as the grouping variables to identify patterns of ocular behavior  
 400 during the first reading. Ward's hierarchical procedure is an agglomerative  
 401 technique that groups data on the basis of their proximity to each other in  
 402 multivariate space. It is therefore used to identify the underlying structure of data.  
 403 The more meaningful and parsimonious solution emerging from the cluster analysis  
 404 was a two-pattern solution. Table 1 reports means and standard deviations of the  
 405 eye-movement indices for the two patterns according to the order of their  
 406 identification using the clustering technique.

407 A MANOVA was carried out to statistically evaluate whether the two patterns  
 408 differed for all the measures considered in the cluster analysis. It revealed a large  
 409 main effect of type of cluster, Wilks' Lambda = .21,  $F(8, 34) = 15.58$ ,  $p < .001$ ,  
 410  $\eta_p^2 = .78$ . Univariate tests showed significant differences only for four measures:  
 411 first-pass fixation time on corresponding text segments,  $F(1, 41) = 58.13$ ,  
 412  $MSE = 1.29$ ,  $p < .001$ ,  $\eta_p^2 = .58$ ; first-pass fixation time on corresponding,  
 413  $F(1, 41) = 5.82$ ,  $MSE = 1.28$ ,  $p = .020$ ,  $\eta_p^2 = .12$ , and non-corresponding picture  
 414 segments,  $F(1, 41) = 13.33$ ,  $MSE = 1.81$ ,  $p = .001$ ,  $\eta_p^2 = .24$ , and first-pass  
 415 transitions from non-corresponding text segments to corresponding picture  
 416 segments,  $F(1, 41) = 5.42$ ,  $MSE = .05$ ,  $p = .025$ ,  $\eta_p^2 = .11$ . Readers characterized  
 417 by pattern 1 attended more the text segments with the central concepts and their  
 418 visualisations, and less the non-corresponding picture segments, than readers who  
 419 showed pattern 2 during the first encounter with the learning material. It is worth



**Table 1** Means and standard deviations of eye-tracking measures as a function of eye-movement patterns of first-pass reading

Indices of first-pass fixation time	Pattern 1: Longer immediate processing (n = 18)		Pattern 2: Shorter immediate processing (n = 25)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
First-pass fixation time on corresponding text segments	8.32	1.26	5.64	1.04
First-pass fixation time on non-corresponding text segments	8.78	1.15	8.43	1.26
First-pass fixation time on corresponding picture segments	8.23	.94	7.39	1.24
First-pass fixation time on non-corresponding picture segments	5.07	1.58	6.59	1.15
First-pass transitions from corresponding text segments to corresponding picture segments	–	–	.05	.19
First-pass transitions from non-corresponding text segments to corresponding picture segments	–	–	.16	.30
First-pass transitions from corresponding picture segments to corresponding text segments	.15	.29	.05	.19
First-pass transitions from non-corresponding picture segments to corresponding text segments	3.83	2.81	6.48	8.94

Measures are log-transformed

420 noting that both patterns of first-pass processing were characterized by very few  
 421 transitions from the verbal to the graphical representation and vice versa. Pattern 1,  
 422 in particular, included readers who did not make any gaze shift from text to picture  
 423 while they were reading the text for the first time.

#### 424 *Patterns of second-pass reading*

425 To answer research question 1, we then focused on the delayed and more purposeful  
 426 second-pass reading or re-processing of verbal and graphical representations. Eight  
 427 indices of eye movements were used as mentioned above: (1) second-pass  
 428 transitions and (2) look-from corresponding text segments to corresponding picture  
 429 segments; (3) second-pass transitions and (4) look-from non-corresponding text  
 430 segments to corresponding picture segments; (5) second-pass transitions and (6)  
 431 look-from corresponding picture segments to corresponding text segments; (7)  
 432 second-pass transitions and (8) look-from non-corresponding picture segments to  
 433 corresponding text segments.

434 Another cluster analysis using the Ward method was performed with the eight  
 435 eye-movement indices as the grouping variables. A two-pattern solution was again  
 436 the more meaningful and parsimonious solution emerging from the cluster analysis.  
 437 Table 2 reports means and standard deviations of the eye-movement indices for the  
 438 two patterns according to the order of their identification using the clustering  
 439 technique.

**Table 2** Means and standard deviations of eye-tracking measures as a function of eye-movement patterns of integrative processing (second-pass reading)

Indices of second-pass fixation time	Pattern 1: Stronger integrative processing (n = 25)		Pattern 2: Weaker integrative processing (n = 18)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Second-pass transitions from corresponding text segments to corresponding picture segments	2.14	.61	.49	.56
Second-pass transitions from non-corresponding text segments to corresponding picture segments	1.67	.81	.77	.65
Second-pass transitions from corresponding picture segments to corresponding text segments	2.12	.82	.39	.47
Second-pass transitions from non-corresponding picture segments to corresponding text segments	1.82	.87	.79	.69
Look-from corresponding text segments to corresponding picture segments	8.62	1.28	3.52	3.77
Look-from non-corresponding text segments to corresponding picture segments	7.85	1.46	2.98	3.89
Look-from corresponding picture segments to corresponding text segments	9.83	1.14	3.26	3.88
Look-from non-corresponding picture segments to corresponding text segments	9.56	1.85	5.89	4.61

Measures are log-transformed

440 A MANOVA was carried out to statistically evaluate whether the two patterns  
 441 differed for all the measures considered in the cluster analysis. It revealed a large  
 442 main effect of type of cluster, Wilks' Lambda = .16,  $F(8, 34) = 21.80$ ,  $p < .001$ ,  
 443  $\eta_p^2 = .83$ . Univariate tests showed significant differences in favour of the pattern of  
 444 stronger integrative processing for all eight fixation indices: (1) second-pass  
 445 transitions from corresponding text segments to corresponding picture segments,  
 446  $F(1, 41) = 79.45$ ,  $MSE = .35$ ,  $p < .001$ ,  $\eta_p^2 = .66$ ; (2) second-pass transitions from  
 447 non-corresponding text segments to corresponding picture segments,  $F(1,$   
 448  $41) = 14.95$ ,  $MSE = .56$ ,  $p < .001$ ,  $\eta_p^2 = .27$ ; (3) second-pass transitions from  
 449 corresponding picture segments to corresponding text segments,  $F(1, 41) = 64.03$ ,  
 450  $MSE = .49$ ,  $p < .001$ ,  $\eta_p^2 = .60$ ; (4) second-pass transitions from non-correspond-  
 451 ing picture segments to corresponding text segments,  $F(1, 41) = 12.93$ ,  
 452  $MSE = 11.31$ ,  $p < .001$ ,  $\eta_p^2 = .30$ ; (5) look-from corresponding text segments to  
 453 corresponding picture segments,  $F(1, 41) = 39.49$ ,  $MSE = 6.88$ ,  $p < .001$ ,  
 454  $\eta_p^2 = .49$ ; (6) look-from non-corresponding text segments to corresponding picture  
 455 segments,  $F(1, 41) = 32.90$ ,  $MSE = 7.55$ ,  $p < .001$ ,  $\eta_p^2 = .44$ ; (7) look-from  
 456 corresponding picture segments to corresponding text segments,  $F(1, 41) = 64.32$ ,  
 457  $MSE = 7.01$ ,  $p < .001$ ,  $\eta_p^2 = .61$ ; (8) look-from non-corresponding picture seg-  
 458 ments to corresponding text segments,  $F(1, 41) = 12.99$ ,  $MSE = 10.85$ ,  $p = .001$ ,  
 459  $\eta_p^2 = .24$ .



460 Research question 2: predicting learning from text by eye-movement patterns  
461 of integrative processing

462 To answer research question 2, we first carried out correlational analyses that  
463 examined the association of all dependent variables with the eye-movement patterns  
464 during the second-pass and first-pass readings. Table 3 displays the correlations  
465 between the variables. Regarding the second-pass reading—which is of primary  
466 concern in this study—all post-reading measures, except text-based factual  
467 knowledge, correlated positively and significantly with eye-movement patterns of  
468 integrative processing. The longer the students' integrative processing of verbal and  
469 graphical information, the better their verbal recall, graphical recall, and transfer of  
470 knowledge. In addition, reading comprehension also correlated positively with all  
471 post-reading measures except verbal recall, whereas prior knowledge correlated  
472 positively with all except the graphical recall. Self-concept correlated positively  
473 with the verbal recall. Note, however, that none of the individual characteristics  
474 correlated with the eye-movement patterns of integrative processing.

475 Regarding the eye-movement patterns of the first-pass reading, correlation  
476 analyses revealed that they neither correlated significantly with the post-reading  
477 measures, nor with the individual characteristics.

478 Successively, to examine whether eye-movement patterns of integrative  
479 processing predicted the various outcomes of text reading after controlling for  
480 reading comprehension, prior knowledge, and self-concept, we carried out a  
481 hierarchical regression analysis for each dependent variable, that is, verbal recall,  
482 graphical recall, text-based factual knowledge and transfer of knowledge. Table 4  
483 reports the scores for all post-reading outcomes.

**Table 3** Zero-order correlations for all variables (N = 43)

Variable	1	2	3	4	5	6	7	8	9
1 Reading comprehension	–								
2 Prior knowledge	.48**	–							
3 Self-concept	.34*	.30*	–						
4 Eye-movement patterns of first-pass	.02	–.18	–.09	–					
5 Eye-movement patterns of second-pass	.09	.15	.19	–.04	–				
6 Verbal recall	.29	.32*	.36*	–.28	.48**	–			
7 Graphical recall	.35*	.14	.11	–.16	.35*	.50**	–		
8 Factual knowledge	.63**	.61**	.27	–.11	.21	.55**	.39**	–	
9 Transfer of knowledge	.46**	.37	.14	–.19	.34*	.51**	.55**	.60**	–

For first-pass eye-movement patterns: 0 = pattern of shorter first-pass, 1 = pattern of longer first-pass

For second-pass eye-movement patterns: 0 = pattern of shorter second-pass, 1 = pattern of longer second-pass

\*  $p < .05$ ; \*\*  $p < .01$



**Table 4** Means and standard deviations of scores for verbal and graphical recalls, factual knowledge, and transfer of knowledge as a function of eye-movement patterns of first- and second-pass reading

	First-pass pattern 1: Longer immediate processing (n = 18)		First-pass pattern 2: Shorter integrative processing (n = 25)		Second-pass pattern 1: Longer integrative processing (n = 25)		Second-pass pattern 2: Longer integrative processing (n = 18)	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Verbal recall	8.66	1.23	11.84	1.08	12.56	1.01	7.66	1.19
Graphical recall	1.41	.14	1.14	.17	1.51	.13	1.01	.16
Factual knowledge	7.83	.66	8.20	.56	8.41	.55	7.54	.65
Transfer of knowledge	4.78	.64	5.79	.54	6.13	.51	4.31	.61

Adjustment for reading comprehension, prior knowledge, and self-concept

484 For each analysis, in the first step reading comprehension, prior knowledge, and  
 485 self-concept were entered into the equation. In the second step, the dummy variables  
 486 of eye-movement patterns of first- and second-pass were entered in all the analyses.  
 487 Results of the regression analyses are reported separately for each post-reading  
 488 outcome.

#### 489 Verbal recall

490 The regression model was significant after entering reading comprehension, prior  
 491 knowledge, and self-concept in the first step,  $R^2 = .19$ ,  $F(3, 39) = 2.94$ ,  $p = .045$ .  
 492 However, none of these individual variables reached significance as a predictor of  
 493 verbal recall. The addition of the eye-movement patterns in the second step resulted  
 494 in a statistically significant increase in the explained variance,  $R^2 = .40$ ,  $F_{\text{change}}(2,$   
 495  $37) = 6.59$ ,  $p = .004$ . Only the patterns of integrative processing during the second  
 496 pass-reading ( $\beta = .41$ ,  $p < .01$ ) predicted retention of text information.  
 497 Table 5(a) summarizes the hierarchical regression analysis for verbal recall.

#### 498 Graphical recall

499 The regression model was not significant after entering reading comprehension,  
 500 prior knowledge, and self-concept in the first step,  $R^2 = .14$ ,  $F(3, 39) = 2.13$ ,  
 501  $p = .111$ , although the first individual factor was a significant predictor of the  
 502 pictorial reproduction ( $\beta = .39$ ,  $p < .05$ ). The addition of the eye-movement  
 503 patterns in the second step resulted in a statistically significant increase in the  
 504 explained variance,  $R^2 = .28$ ,  $F_{\text{change}}(2, 37) = 3.73$ ,  $p = .033$ . Only the patterns of  
 505 integrative processing during the second-pass reading ( $\beta = .32$ ,  $p < .05$ ) predicted  
 506 the recall of graphical elements. Reading comprehension was also a predictor  
 507 ( $\beta = .43$ ,  $p < .05$ ). Table 5(b) summarizes the hierarchical regression analysis for  
 508 graphical recall.





**Table 5** Results of hierarchical regression analyses for variables predicting verbal recall, factual knowledge and transfer

Predictor	$\Delta R^2$	$\beta$
<i>(a) Verbal recall</i>		
Step 1	.19*	
Reading comprehension		.05
Prior knowledge		.24
Self-concept		.25
Step 2	.21*	
Reading comprehension		.09
Prior knowledge		.13
Self-concept		.19
First-pass eye-movement patterns		.26
Second-pass eye-movement patterns		.41**
Total $R^2$	.40*	
$N$	43	
<i>(b) Graphical recall</i>		
Step 1	.14	
Reading comprehension		.39*
Prior knowledge		-.07
Self-concept		.04
Step 2	.14*	
Reading comprehension		.43*
Prior knowledge		-.19
Self-concept		.01
First-pass eye-movement patterns		.23
Second-pass eye-movement patterns		.32*
Total $R^2$	.28*	
$N$	43	
<i>(c) Factual knowledge</i>		
Step 1	.53***	
Reading comprehension		.44**
Prior knowledge		.40**
Self-concept		-.00
Step 2	.01	
Reading comprehension		.45**
Prior knowledge		.37**
Self-concept		-.02
First-pass eye-movement patterns		.05
Second-pass eye-movement patterns		.12
Total $R^2$	.54***	
$N$	43	

Table 5 continued

Predictor	$\Delta R^2$	$\beta$
<i>(d) Transfer of knowledge</i>		
Step 1	.25*	
Reading comprehension		.39*
Prior knowledge		.20
Self-concept		-.05
Step 2	.12*	
Reading comprehension		.42*
Prior knowledge		.11
Self-concept		-.10
First-pass eye-movement patterns		.19
Second-pass eye-movement patterns		.32*
Total $R^2$	.37*	
<i>N</i>	43	

\*  $p < .05$ ; \*\*  $p < .01$ ;\*\*\*  $p < .001$ 

## 509 Text-based factual knowledge

510 The regression model was significant after entering the three individual factors in  
 511 the first step,  $R^2 = .53$ ,  $F(3, 39) = 14.54$ ,  $p < .001$ . Both reading comprehension  
 512 and prior knowledge were predictors of the acquisition of factual knowledge  
 513 ( $\beta = .44$ ,  $p < .01$  and  $\beta = .40$ ,  $p < .01$ , respectively). The addition of eye-  
 514 movement patterns in the second step did not result in a statistically significant  
 515 increase in the explained variance,  $R^2 = .54$ ,  $F_{\text{change}} < .1$ . Patterns of integrative  
 516 processing did not predict this level of illustrated text comprehension.  
 517 Table 5(c) summarizes the hierarchical regression analysis for factual knowledge.

## 518 Transfer of knowledge


519 The regression model was significant after entering reading comprehension, prior  
 520 knowledge, and self-concept in the first step,  $R^2 = .25$ ,  $F(3, 39) = 4.31$ ,  $p = .010$ .  
 521 Specifically, reading comprehension was a predictor of the deeper level of learning  
 522 from text ( $\beta = .39$ ,  $p < .05$ ). The addition of the eye-movement patterns in the  
 523 second step resulted in a statistically significant increase in the explained variance,  
 524  $R^2 = .37$ ,  $F_{\text{change}}(2, 37) = 3.59$ ,  $p = .037$ . Only the patterns of integrative  
 525 processing during the second-pass ( $\beta = .32$ ,  $p < .05$ ) again predicted learning  
 526 from illustrated text. Reading comprehension was also a predictor ( $\beta = .42$ ,  
 527  $p < .05$ ). Table 5(d) summarizes the hierarchical regression analysis for transfer of  
 528 knowledge.

## 529 Discussion

530 This study sought to extend current research on processing of text and graphics that  
 531 is associated with successful learning from science text in lower-secondary school,



532 in two main ways. First, we distinguished between eye-movement patterns of  
 533 immediate and more automatic first-pass reading from the eye-movement patterns  
 534 of delayed and more purposeful second-pass reading. Second, we examined whether  
 535 the latter uniquely predicted the off-line measures of reading, after controlling for  
 536 important individual differences, to reveal the link between visual attention and  
 537 learning from illustrated text more closely.

538 The first research question asked what distinct eye-movement patterns of  
 539 processing of verbal and graphical information would emerge when considering  
 540 various indices of the immediate first-pass reading and the delayed second-pass  
 541 reading. As concerns the former, two eye-movement patterns were identified  
 542 through a cluster analysis. Readers differed for the time spent on the visualized text  
 543 segments and the overall picture during the first encounter with the learning  
 544 material. As concerns the delayed processing, two patterns of eye movements also  
 545 emerged. As expected, they differed for the extent to which the readers were  
 546 involved in shifting from text to picture and from picture to text, and re-reading text  
 547 segments while re-inspecting picture segments and re-inspecting picture segments  
 548 while re-reading text segments. This re-processing reflects integration of verbal and  
 549 graphical information, which occurred rarely during the first-pass in both patterns.  
 550 Integrative re-processing has been indicated as more critical than the immediate  
 551 processing in multimedia learning (Masou  uchino et al., 2003; Mason et al.,  
 552 2013d).

553 The second research question asked whether only readers' eye-movement  
 554 patterns of integrative processing would predict various post-reading outcomes after  
 555 controlling for the individual characteristics of reading comprehension, prior  
 556 knowledge, and self-concept. As expected, the results of the regression analyses  
 557 showed that only eye-movement patterns of integrative processing characterizing  
 558 the second-pass reading uniquely predicted the verbal and graphical recalls and  
 559 deeper learning from text in the transfer task, after controlling for individual  
 560 characteristics. More specifically, verbal recall was predicted only by eye-  
 561 movement patterns after controlling for the latter. Graphical recall and transfer of  
 562 knowledge were predicted by eye-movement patterns over and above reading  
 563 comprehension. For all post-reading outcomes predicted by these patterns, the  
 564 longer the students' integrative processing of text and graphics during the second-  
 565 pass reading, the higher their performances.

566 It should be pointed out that only one post-reading performance, the acquisition  
 567 of text-based factual knowledge, was not predicted by the patterns of integrative  
 568 processing. It is unclear why this measure—which required comprehension at the  
 569 level of a locally and globally coherent representation of the propositions introduced  
 570 in the text—was predicted only by participants' reading proficiency and what they  
 571 already knew about the topic. This issue needs further investigation. A possible  
 572 interpretation is that the questions used to measure factual knowledge did not  
 573 require particular integration of verbal and graphical elements.

574 It is worth noting that the eye-movement patterns of first-pass reading did not  
 575 predict any outcome measure. This means that the immediate and more automatic  
 576 processing of the instructional material contributed to neither less deep, nor to  
 577 deeper learning from text.

578 In sum, the study provides further evidence of the multimedia principle (Mayer,  
 579 2009; Butcher, 2014), indicating that only the patterns of integrative processing of  
 580 verbal and graphical information during the second-pass are associated with  
 581 retention and transfer of knowledge. This outcome extends the findings of previous  
 582 eye-tracking studies with older (Johnson & Mayer, 2012; Stalbovs et al., 2013) and  
 583 younger students (Mason et al., 2013d), and to some extent indirectly, also the  
 584 findings of outcome-oriented studies that designed instruction to sustain learning  
 585 from text and graphics (Bartholomé & Bromme, 2009; Florax & Ploetzner, 2010;  
 586 Schlag & Ploetzner, 2011).

587 Nevertheless, the present study also has limitations that should be taken into  
 588 consideration when interpreting the findings. Similarly to almost all eye-tracking  
 589 studies, which are particularly laborious, the sample size is modest and a larger one  
 590 would be more optimal. In addition, because of technical constraints related to the  
 591 use of the index of the look-from fixation time, a short text illustrated by one picture  
 592 presented on only one screen was used. However, we can speculate that if the  
 593 relevance of integrative processing emerged clearly for limited material, it could be  
 594 even more critical when considering longer texts accompanied by multiple  
 595 instructional pictures.

## 596 Conclusion and significance

597 Despite these limitations, the present study has theoretical significance as it not only  
 598 confirms, but also extends previous investigations, providing evidence that deeper  
 599 learning from an illustrated text is predicted only by integrative processing of verbal  
 600 and graphical information in their corresponding and non-corresponding segments.  
 601 This processing occurs during a delayed, less automatic and more purposeful  
 602 allocation of visual attention when re-reading text parts while re-inspecting picture  
 603 parts and vice versa.

604 The importance of reading behavior after the first encounter with the instructional  
 605 material also underlines the educational significance of the study. In this regard, two  
 606 implications can be drawn. First, teachers should believe that integrative processing  
 607 is essential, even when brief or simple material is to be learned, in order to  
 608 emphasize it to their students (Schroeder et al., 2011).

609 The second educational implication highlights the need for students to be  
 610 metacognitively aware that pictures should not be disregarded or processed only  
 611 superficially. One possible way to increase this metacognitive awareness is to show  
 612 students the replays of their eye movements during reading (Mikkilä-Erdmann,  
 613 Penttinen, Anto, & Olkinuora, 2008). Modern eye trackers not only provide unique  
 614 information regarding perceptual and cognitive processes underlying learning  
 615 performance, but they also make gaze replays available in videos. Low-integrator  
 616 readers can observe the video of their ocular behavior and reflect upon how they  
 617 allocated their visual attention on the instructional material. In this way they can be  
 618 supported to create or refine metacognitive awareness that their ability to integrate  
 619 text and picture makes a difference to learning outcomes.

620

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