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Does reading medium affect processing and integration of textual and pictorial information? A multimedia eye-tracking study

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ABSTRACT

This study investigated effects of reading medium (print vs. digital) on integrative processing and integrated understanding of an illustrated text on human sexuality, as well as whether reading medium indirectly affected integrated understanding via integrative processing. Participants were 100 undergraduate and graduate students in educational sciences. Integrative processing was indicated by participants' gaze transitions between complementary textual and pictorial parts of the document during reading, and integrated understanding was indicated by participants' integration of textual and pictorial information in post-reading written responses. Results showed that participants who read the illustrated text on paper displayed more integrative processing during reading than did participants who read exactly the same text on a computer. In turn, integrative processing positively affected comprehension performance, resulting in a mediated effect of reading medium on comprehension via integrative processing. There was no main effect of reading medium on integrated understanding, however. Also, prompting participants to pay attention to both text and illustration as well as their relationship did not have any main effects on integrative processing or integrated understanding; nor were there any interaction effects of reading medium with instructional prompt on integrative processing or integrated understanding. These results are discussed in terms of the insights they offer into reading medium effects on processing and comprehension, as well as in terms of the directions they suggest for future research in this area.

1. Introduction

During the last decade, there has been a revival of interest in the reading of printed versus digital texts, with a focus on potential differences in processing and comprehension. Regarding comprehension, a series of recent reviews has indicated that reading medium affects comprehension, with reading in print leading to better comprehension performance than reading digitally (Clinton, 2019; Delgado, Vargas, Ackerman, & Salmerón, 2018; Kong, Seo, & Zhai, 2018; Singer & Alexander, 2017b). Delgado et al. (2018) included 16 within-participants and 38 between-participants studies in their meta-analysis, with all studies comparing the comprehension of texts that differed only with regard to the reading medium. These authors found an advantage for printed texts that corresponded to a Hedge's *g* of 0.21. Two other recent meta-analyses (Clinton, 2019; Kong et al., 2018) obtained similar effect sizes in the favor of printed texts. The meta-analysis conducted by Delgado et al. (2018) also documented that the advantage of reading in print was greater when the reading time was restricted, when people read informational texts, and when the studies were presented or published more recently (i.e., since 2000).

Regarding processing, readers have been found to invest less time in reading digital compared with printed texts, as well as to be less accurate in their judgments of their actual level of comprehension in the former reading context (Singer & Alexander, 2017a; Singer Trakhman, Alexander, & Berkowitz, 2019; Ackerman & Goldsmith, 2011; Lauterman & Ackerman, 2014). The relationship between reading time and calibration may well be bidirectional. On the one hand, faster, less careful reading of digital texts may increase the tendency to overestimate actual comprehension performance (Singer Trakhman et al., 2019); on the other hand, readers may read digital texts faster than printed texts because they overestimate their comprehension of the former and therefore do not see any need to spend time regulating their text processing (Ackerman & Goldsmith, 2011; Lauterman & Ackerman, 2014).

Both shorter reading times and poorer calibration for digital than for printed texts are consistent with the shallowing hypothesis (Annisette & Lafreniere, 2017) used to explain the comprehension advantages of printed texts. The foundation of this hypothesis was

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eloquently described by Carr (2011) in this way:

> … when we go online, we enter an environment that promotes cursory reading, hurried and distracted thinking, and superficial learning. It's possible to think deeply while surfing the Net, just as it's possible to think shallowly while reading a book, but that's not the type of thinking the technology encourages and rewards (p. 116).

In other words, the shallowing hypothesis is built on the premise that people's use of digital media, including the Internet, typically involves quick interactions driven by immediate rewards. Over time, such interactions may establish a habit of mind that leads people to process digital texts more shallowly and superficially than printed texts. More generally, this habit of mind may constrain performance of more challenging tasks requiring sustained attention, of which text comprehension is only one example (Annisette & Lafreniere, 2017; see also, Delgado et al., 2018; Latini, Bråten, Anmarkrud, & Salmerón, 2019).

Thus far, however, direct evidence for the shallowing hypothesis is essentially lacking. The aim of the current study was to provide such evidence by using eye tracking to measure students' processing while reading digital and printed information, respectively, also examining the extent to which the effect of reading medium on comprehension performance was mediated by students' processing during reading as evidenced by their eye movements. Because students more often than not learn from multimedia involving various external representations, we focused on their integrative processing of textual and graphic information and the relationship between such processing and achieving an integrated understanding of the topic in question: The physiology of human sexuality. Hopefully, the current extension of research on the effects of reading medium to the processing and comprehension of textual and graphic information may enrich research on reading medium as well as on multimedia learning, broadening the research agenda in both areas and providing new insights into the challenges facing "the modern reader" (Magliano, McCrudden, Rouet, & Sabatini, 2018).

Before we further delineate the unique aspects of the current research and the specific hypotheses that guided our work, we briefly discuss relevant theory concerning the processing of and learning from multimedia content and review prior research on integrative processing and comprehension of textual and graphic information using eye tracking technology. Because we also explored whether instructional prompts might moderate the effects of reading medium on the processing and comprehension of textual and graphic information, a brief discussion of this approach is also included in our background analysis.

1.1. Multimedia learning: relevant theory and prior research

1.1.1. Cognitive theory of multimedia learning

Several theoretical frameworks are relevant to understanding learning with and from multimedia, for example, the integrated model of text and picture comprehension by Schnotz (2014; Schnotz & Bannert, 2003) and the design, functions, and tasks framework for learning with multiple representations by Ainsworth (2006, 2014). Still, Mayer's (2005, 2014) cognitive theory of multimedia learning is arguably the most influential model for explaining the role of integration in multimedia learning and comprehension. According to this model, words, including spoken and written words, and pictures, including static graphics (e.g., photos and diagrams) and dynamic graphics (e.g., animations and videos), are actively processed in separate information processing channels of limited capacity. This processing involves building a coherent mental representation based on verbal information and a coherent mental representation based on pictorial information in working memory, and then integrating these separate verbally based and pictorially based representations with each other and with relevant prior knowledge activated from long-term memory. According to Mayer (2014), the most crucial step in meaningful learning from multimedia may be the creation of an integrated representation in which corresponding or relevant parts of the verbal and pictorial representations are mapped onto each other. The cognitive processing resulting in an integrated mental representation is termed "generative" because it is aimed at generating new understanding based on the presented multimedia materials.

The multimedia principle refers to the assumption that people learn more effectively and deeply with words and pictures than with words or pictures alone (Butcher, 2014). However, the applicability of this basic principle is dependent on several other principles of multimedia learning, including the coherence principle stating that unnecessary information should be removed, the spatial and temporal contiguity principles stating that words (written or spoken) and pictorial information should be presented spatially and temporally near each other, the redundancy principle stating that written text should not be added to spoken text, and the signaling principle stating that essential materials should be highlighted (Mayer, 2019). According to Mayer (2003), there is evidence to suggest that such principles of multimedia learning, including the basic multimedia principle, hold regardless of whether the multimedia content is presented in print (i.e., as written words and static graphics) or digitally (i.e., as spoken words and animations). It is still an important unanswered question, however, whether the medium (i.e., print vs. digital) may affect the generative, integrative processing of multimedia information and, thereby, the construction of a mental representation that integrates verbal and pictorial content.

1.1.2. Eye tracking research on integrative processing and learning in a multimedia context

Mayer's cognitive theory of multimedia learning highlights the need for online measurement of processing, with eye tracking representing a promising methodology in this regard (Mayer, 2019). Based on the assumption that information being visually attended to (fixated) is simultaneously being cognitively processed (Just & Carpenter, 1980), eye tracking may provide quantitative and objective information about learners' efforts to relate or link elements of the learning materials, including textual and pictorial elements, during multimedia learning (Hyönä, 2010; Hyönä, Lorch, & Rinck, 2003). In other words, the switching of attention between elements of different external representations (e.g., text and pictures) can be taken as evidence for integrative processing of these elements (Hyönä, 2010).

Mason and her colleagues have been at the forefront of eye tracking research on integrative processing during multimedia learning (e.g., Mason, Pluchino, & Tornatora, 2013a, 2015a, 2016; Mason, Scheiter, & Tornatora, 2017; Mason, Tornatora, & Pluchino, 2013b, 2015b). In this work, which has focused on the reading of illustrated science text, integrative processing has been measured by the duration of the fixations on corresponding pictorial elements while reading the text and the duration of the fixations on corresponding textual elements while inspecting the picture, as well as by the number of times fixations shift between corresponding textual and pictorial elements. Results have generally shown that both the cross-representational fixation times and the number of cross-representational transitions are positively associated with learning outcomes, most notably with the performance on tasks requiring that learners apply the acquired knowledge to new problems (Mason et al., 2017; Mason et al., 2013a, 2015a; Mason et al., 2013b, 2015b). Of note is that results based on cross-representational fixation times and results based on number of cross-representational transitions seem highly consistent in this body of work, with very high correlations between the two types of eye tracking measures indicating that they actually capture the same construct of integrative processing of textual and pictorial information (Mason et al., 2017; Mason et al., 2013a, 2016).

As an example of corroborating evidence from another lab, Stalbovs, Scheiter, and Gerjets (2015) found that students' number of gaze transitions between corresponding elements of text and pictures in an illustrated science text predicted their performance on a broad outcome measure containing items that targeted retention as well as comprehension of textual information, pictorial information, or both. Whereas Mason and colleagues used illustrated texts in which the texts described the same information that was depicted in the illustration, Stalbovs et al. (2015) used an illustrated text in which textual and pictorial information was somewhat different and both needed to gain a complete understanding of the scientific topic in question. Thus, in the terminology of Ainsworth (2006, 2014), the multimedia materials presented by Mason and colleagues were complementary in the sense that text and pictures referred to the same information but represented it in different (i.e., complementary) ways, whereas the multimedia materials presented by Stalbovs et al. (2015) were complementary in the sense that text and pictures offered different (i.e., complementary) information about the topic.

Finally, in a recent systematic review of eye tracking research on multimedia learning, Alemdag and Cagiltay (2018) found that studies examining integrative processing through learners' transitions between corresponding elements of textual and pictorial information generally reported statistically significant correlations with learning outcome measures. However, these authors also pointed to a lack of studies investigating relationships between eye tracking measurements and multimedia learning outcomes, with only half of the 58 studies they reviewed providing such information. Moreover, among the studies examining cross-representational transitions, in particular, none of the studies seem to have directly investigated the relationship between such integrative processing and performance on comprehension measures specifically designed to capture the integration of textual and pictorial information (this includes the studies by Mason and colleagues and Stalbovs et al. that were cited above). Because all prior eye tracking research on multimedia learning has presented the materials only in a digital environment, this research, of course, cannot answer the question of whether there are any medium effects on integrative processing and the comprehension products resulting from such processing.

1.2. Instructional prompts in the context of multimedia learning

Despite the potential benefits of combining textual and pictorial information, students often tend to skim or skip over pictorial information and invest most of their time and effort in processing the text when reading illustrated science text (Cromley, Snyder-Hogan, & Luciw-Dubas, 2010; Hannus & Hyönä, 1999; Schwonke, Berthold, & Renkl, 2009). Reasons for this imbalance may be that students deem the textual information to be more important or relevant, that they are not aware of the role and importance of pictorial information for understanding science texts, or that they find the pictorial information difficult to understand (Cromley et al., 2010; Schwonke et al., 2009). There are several viable paths to promoting students' attention to and effective use of pictorial information, such as teaching them about the conventions used in diagrams (Bergey, Cromley, Kirchgessner, & Newcombe, 2015; Cromley et al., 2013, 2016; Miller, Cromley, & Newcombe, 2016), simplifying the illustrations (Butcher, 2006; Mason, Pluchino, Tornatora, & Ariasi, 2013), labeling illustrations in ways that facilitate the mapping of corresponding elements of textual and pictorial information onto each other (Mason et al., 2013a), and modeling a more balanced and integrative processing of illustrated text (Mason et al., 2017; Mason et al., 2015a, 2016). Yet another approach is to try to increase learners' awareness of the importance of the pictorial information and the need to integrate this information with relevant elements of the text by means of instructional prompts.

Instructional prompts are directives that aim at guiding learners' attention to and processing of the learning materials, for example by explicitly informing them about the importance of particular information and how to respond to it (e.g., Bartholomé & Bromme, 2009; Stalbovs et al., 2015; Van Meter, Cameron, & Waters, 2017). In the context of multimedia learning, instructional prompts may thus take the form of explicitly telling learners to pay attention to pictorial as well as textual information and to try to integrate pictorial and textual information in the meaning making process. Accordingly, Van Meter et al. (2017), who had college students read a text about human physiology that also included a number of diagrams, provided some of the students with a "diagram awareness prompt" that told them to pay attention to both the text and the diagrams and to think about how they were related. The results indicated that increasing learners' awareness of the diagrams and text-diagram relations by means of this instructional prompt especially improved their performance on learning tasks assessing knowledge gained from diagrams and from text-diagram relations (Van Meter et al., 2017).

Of note is that an instructional prompt such as the diagram awareness prompt used by Van Meter et al. (2017) is consistent with the signaling principle established within multimedia learning research. Thus, this principle highlights the potential benefits of providing cues that guide learners' attention to important or relevant information and the organization of the multimedia learning materials (van Gog, 2014). In the current study, we explored whether an instructional prompt cueing students to pay attention to diagram-based information and diagram-text relations might moderate the effects of reading medium on students' integrative processing and comprehension of illustrated text.

1.3. Controlling for individual differences

Because our study addressed questions concerning the effects of reading medium and instructional prompts rather than individual differences, we wanted to control for the potential influences of intrinsic motivation, reading comprehension, and diagram comprehension. These variables were regarded as relevant covariates because prior research has suggested that they may be associated with integrative processing as well as comprehension of multiple information resources (e.g., Bråten, Anmarkrud, Brandmo, & Strømsø, 2014; Mason et al., 2016; Mason et al., 2015b; Van Meter et al., 2017; Wang, Tsai, & Tsai, 2016). Thus, reading comprehension may influence integrative processing by facilitating the building of a coherent mental representation based on verbal information, which is consistent with theoretical assumptions as well as empirical findings within reading research (McNamara & Magliano, 2009b). Consistent with theoretical assumptions and empirical findings within multimedia learning (Mayer, 2014; Van Meter et al., 2017), diagram comprehension may influence integrative processing by facilitating the building of a coherent mental representation based on pictorial information. Presumably, both these individual difference variables may also be directly related to an integrated understanding of the multimedia materials (Mason et al., 2015b; Van Meter et al., 2017). Finally, a willingness to work with the learning material because it is experienced as enjoyable or interesting in its own right (i.e., task-based or situational intrinsic motivation; Deci & Ryan, 2000; Schiefele, Schaffner, Möller, & Wigfield, 2012) is likely to make learners invest more effort in integrative processing and achieve a more integrated understanding of the verbal and pictorial information. Recently, the importance of affective engagement has been highlighted within frameworks addressing learning from multiple information sources (List & Alexander, 2017, 2019), and empirical work has indicated that learners' situational interest and engagement in the learning task actually may explain integrated understanding over and above pertinent cognitive variables (Bråten, Brante, & Strømsø, 2018; List, Stephens, & Alexander, 2019).

1.4. The present study

On the basis of theoretical assumptions and empirical work discussed in previous sections, this study uniquely contributes to research on the effects of reading medium by investigating the extent to which both integrative processing and integrated understanding of multimedia content differs when learners read a printed, as opposed to a digital document. Building on the shallowing hypothesis (Annisette &

Lafreniere, 2017; Delgado et al., 2018), as well as relevant prior research consistent with this hypothesis (e.g., Ackerman & Goldsmith, 2011; Lauterman & Ackerman, 2014; Singer Trakhman et al., 2019), we hypothesized that participants who read an expository illustrated text about the physiology of sexuality on paper would display more integrative processing and more integrated understanding of the content than would participants who read the same information in a digital document. In addition, we hypothesized that participants prompted to pay particular attention to both text and illustration as well as their relationship would display more integrative processing and more integrated understanding than would participants who were not given a diagram awareness prompt (Van Meter et al., 2017). Regarding both integrative processing and integrated understanding, we also entertained the possibility that the effects of reading medium might be moderated by the instructional prompt, with a diagram awareness prompt presumably reducing the effects of reading medium on integrative processing and integrated understanding, respectively.

Finally, we hypothesized that participants' integrative processing, as evidenced by their eye movements, would mediate the potential effect of reading a printed versus a digital document on their integrated understanding of document information, as evidenced by their written products. Presumably, when reading a printed document, as compared to a digital document, participants' eye movements would show more transitions among relevant (i.e., complementary) parts of the verbal and pictorial representations included in the document. Consistent with the cognitive theory of multimedia learning by Mayer (2005, 2014), highlighting the importance of generative processing in multimedia learning, as well as prior eye tracking research showing that number of transitions between corresponding elements of text and pictures are positively related to learning performance (e.g., Mason et al., 2017; Stalbovs et al., 2015; for review, see Alemdag & Cagiltay, 2018), we considered it likely that participants who performed more cross-representational transitions would also display more integrated understanding of document content in their written products. Consequentially, a mediated effect of reading medium on integrated understanding could be expected.

By including task-based intrinsic motivation, reading comprehension, and diagram comprehension as covariates, we wanted to ensure that any effects of our experimental manipulations occurred independently of these individual difference variables.

2. Method

2.1. Participants

Participants were 100 undergraduate and graduate students in educational sciences from a large public university in southeast Norway, with 55% enrolled in the third year of a bachelor program and 45% enrolled in the first and second years of a master program. The mean age of the participants was 24.91 years (*SD* = 3.79) and 82.4% were female. The vast majority (86%) had Norwegian as their first language, and the rest were bilingual. With respect to reading medium, participants reported that they preferred reading printed rather than digital materials in the study context as well as in their leisure time. Moreover, participants perceived their knowledge about the relevant domain of human physiology to be relatively low.[1]

Participants were recruited from regular lectures and volunteered to participate in the study. They received a gift card worth NOK 200 (approx. USD 25) for their participation. Collection and handling of all data met the requirements of the Personal Data Registers Act and were approved by the Norwegian Social Science Data Services.

2.2. Materials

2.2.1. Document and experimental manipulations

Each participant read one illustrated text titled "The physiology of sexuality." The illustrated text was created on the basis of various authentic materials on the topic, including an introductory psychology textbook and diverse popular science articles. We adapted these materials in regard to language and length to create a single document consisting of verbal as well as pictorial information. In the upper right corner of the document, source information was presented in the form of author's name and credentials and date of publication. The document was presented as taken from a Norwegian popular science website (forskning.no), published in late November 2018, and authored by a female research reporter with a common Norwegian name. The document consisted of 320 words of text and a diagram. The readability of the text was computed using Björnsson (1968) formula, which is based on word and sentence length. A readability of 53 indicated that the text was comparable to the difficulty level of specialized literature (Björnsson, 1983).

The document consisted of six paragraphs of text, a diagram, and a figure caption. The first paragraph (approx. 50 words) presented a general introduction to the topic of human sexuality. The second paragraph (approx. 50 words) introduced the classic study of human sexual responses by Masters and Johnson (1966), and the third paragraph (approx. 50 words) described the four phases of the sexual response cycle according to these authors (i.e., excitement, plateau, orgasm, and resolution) and mentioned that the sexual response cycle in females can have alternative patterns. Following these three paragraphs, the document contained a diagram displaying three different female sexual response cycles, which were labeled A, B, and C in the diagram. These labels were explained in a figure caption of approximately 30 words, which was located to the right of the diagram. Pattern A was said to illustrate the experience of one or more orgasms followed by resolution, pattern B was said to illustrate the experience of a plateau phase with no orgasm, and pattern C was said to illustrate the experience of an orgasm without any preceding plateau phase. Underneath the diagram, the fourth paragraph (approx. 60 words) described the typical sexual response cycle of males. Of note is that this cycle was not displayed in the diagram or mentioned in the figure caption. The fifth paragraph (approx. 30 words) included information about the prevalence of the different female response cycles displayed in the diagram, only referring to these cycles by their labels (e.g., "… 24% of Norwegian women report that they for a longer period of time experience a sexual response cycle corresponding to pattern B"). Finally, the sixth paragraph (approx. 45 word) contained a general conclusion regarding human sexuality. An English version of the document is presented in Appendix A.

The reading medium was manipulated between participants, such that participants (randomly assigned) read the document in print or on screen. In the print condition, the six paragraphs of text and the figure caption were printed single spaced using 11 point Verdana, with the diagram and the figure caption inserted between the third and the fourth paragraphs. The size of the diagram was equivalent to 17 lines of single spaced text. The text and the diagram was presented on one A4 (8.3 × 11.7 in.) sheet of paper. In the digital condition, participants read exactly the same document as a PDF file with Adobe Reader on a desktop computer with an 24″ LCD monitor at a resolution of 1920 × 1200 pixels and a font size equivalent to 11-points size. The entire document was available on the screen at once, meaning there was no need for scrolling. Further, we manipulated the instructional

[1] On a demographic survey, participants rated their preference for reading medium when reading in the study context and in their leisure time on a scale ranging from 1 to 5 (1 = clear preference for digital materials, 5 = clear preference for printed materials). For the study context, their mean score was 4.39 (*SD* = 0.72), and for their leisure time, the mean score was 3.78 (*SD* = 1.28). In addition, they rated their knowledge about human physiology on a scale ranging from 1 (no knowledge) to 10 (expert), obtaining a mean score of 3.91 (*SD* = 1.40).

prompt between participants, such that participants (randomly assigned) were either given a diagram awareness prompt (Van Meter et al., 2017) directing their attention to the diagram and text-diagram relations, or were just instructed to base their written response on the illustrated text (see *Procedure* below).

2.2.2. Eye tracking apparatus and areas of interest

To measure participants' eye-movements while reading the document, we used a pair of eye tracking glasses provided by SensoMotoric Instruments, which has a sampling rate of 30 Hz. These glasses are worn as a pair of normal glasses, with a tightening strap for stability. The glasses utilize an event detection algorithm that identifies saccades and blinks, and classifies the remaining samples as visual intake or fixation. Fixations shorter than 50 ms are excluded and a preprocessing algorithm corrects for head movements. Of note is that the design of this study, involving the reading of both printed and digital materials, required an eye tracking apparatus that was suitable for measuring eye movements across the two reading mediums.

To analyze participants' eye movements, we defined a set of 10 areas of interest (AOI), which corresponded to the title of the document, the source information, the six paragraphs of text described previously, the diagram, and the figure caption. The sizes and spatial relationships between these AOIs made them suitable as units of analysis given the eye tracking apparatus that we used.

2.2.3. Dependent measures

In the following, we describe our two dependent measures: integrative processing during reading and integrated understanding of the document content. Regarding the latter, we also describe the scoring system and how interrater reliability was established.

2.2.3.1. Integrative processing. As a measure of integrative processing during reading, we computed the number of times participants' eye fixations shifted between corresponding (i.e., complementary) textual and pictorial parts of the document. Specifically, we computed a total transition score based on the number of gaze transitions from the AOIs defined by the third, fourth, and fifth paragraphs of text to the AOI defined by the diagram and vice versa, the number of gaze transitions from the AOI defined by the diagram to the AOI defined by the figure caption and vice versa, and the number of gaze transitions from the AOIs defined by the third, fourth, and fifth paragraphs of text to the AOI defined by the figure caption and vice versa. To gain a complete understanding of the content of the document, information from these three paragraphs of text, the diagram, and the figure caption had to be combined. For example, the alternative patterns of the sexual response cycle in females mentioned in the third paragraph were displayed in the diagram, and the A, B, and C labels included in the diagram were further explained in the figure caption. Such gaze transitions between corresponding elements of text and pictures have been validated as a measure of integrative processing in several previous studies (e.g., Mason et al., 2017; Mason et al., 2013a, 2016; Stalbovs et al., 2015). Of note is that in this document, corresponding elements of textual and pictorial information were complementary in the sense that they were required to gain a complete understanding of the document content, with related information split across different representations (Ainsworth, 2014).

2.2.3.2. Integrated understanding. To measure integrated understanding of the document content, we asked participants to write a report in which they explained similarities and differences between men and women's sexual response cycles based on the illustrated text. Responses were scored according to the number of relevant idea units from the document that were included in the report, with extra points awarded for idea units that combined information from the textual and pictorial representations. Specifically, the document contained nine unique idea units relevant to explaining similarities and differences between males and females' sexual responses. Two of these idea units concerned similarities between males and females (e.g., males and females experience four stages during sexual activity), five concerned differences between males and females (e.g., males experience a refractory period), and two concerned elaborations of the female patterns labeled A and B, respectively. For three of these idea units, two concerning similarities and one concerning differences, participants were given a score of 0 or 1 depending on whether the idea units were or were not represented in their report. For four of the idea units concerning differences, participants' scores ranged from 0 to 2, with a score of 0 reflecting that this idea unit was not represented in the report, a score of 1 reflecting that this idea unit was represented in the report but referred to the sexual response cycle of either males or females, and a score of 2 reflecting that this idea unit was represented in the report and referred to (i.e., compared) the sexual response cycles of males and females. Likewise, participants' scores ranged from 0 to 2 for the idea units concerning the female patterns labeled A and B, with a score of 0 reflecting that this idea unit was not represented in the report, a score of 1 reflecting that this idea unit was represented in the report without any further elaboration of the pattern in question, and a score of 2 reflecting that this idea unit was represented in the report as well as further elaborated. Importantly, receiving a score of 2 always required the combination of textual and pictorial information from the document. Accordingly, participants' scores on this measure provided information about the extent to which they had achieved an integrated understanding of the document content. We further describe and exemplify this scoring system in Appendix B.

The first and second authors, blind to experimental conditions, scored the written responses of all participants. First, they scored the responses of 20 participants in collaboration. Next, they scored a random selection of 20 participants' responses (i.e., 20%) independently, which resulted in a high interrater reliability estimate (Cohen's Kappa = 0.89). Also, the raters' total scores for the 20 participants were highly correlated (Pearson's $r = 0.95$). All disagreements were solved in discussion, and these two authors scored the responses of the remaining participants separately. The scores on the entire measure could possibly range from 0 to 15. In subsequent statistical analyses, only the total scores were used.

2.2.4. Covariates

We included measures of task-based intrinsic motivation, reading comprehension, and diagram comprehension ability as potential covariates.

2.2.4.1. Task-based intrinsic motivation. To measure task-based intrinsic motivation, we used a five-item inventory developed by Bråten, Johansen, and Strømsø (2017), which participants completed immediately following their reading of the document. On this inventory, participants rated to what extent they had experienced reading the document as exciting, interesting, fun, attractive, and enjoyable (sample items: I felt that the text that I just read was exciting; I was interested in understanding what I read in this text). Participants rated each item on a 5-point scale ranging from *does not fit at all* (1) to *fits very well* (5). Prior research has shown that such current (rather than habitual) intrinsic motivation, concerning the willingness to engage in a specific reading task in a given situation, may be associated with strategic processing as well as with performance (Schiefele et al., 2012; Wigfield & Cambria, 2010). Scores on the measure were divided by the number of items so that they ranged from 1 to 5. The reliability estimate for scores on this measure (Cronbach's alpha) was 0.81.

2.2.4.2. Reading comprehension measure. We administered a Norwegian version of a cloze-type reading comprehension measure developed and validated in Danish by Gellert and Elbro (2013). The Norwegian version was validated by Latini et al. (2019), who found undergraduates' scores to be highly correlated with their text integration in a multiple text reading task. Five narrative and five expository texts were included in the measure. These texts ranged from 40 to 330 words, with a total of 1,340 words. The 10 texts contained 41 word gaps with four alternative words provided for each gap, and correct refilling of the gaps could only be achieved by drawing bridging inferences. Participants were given 10 min to read the texts and refill as many gaps as possible. Participants' scores were the number of correctly refilled gaps (maximum score = 41). Cronbach's α for participants' scores was 0.83.

2.2.4.3. Diagram comprehension measure. To measure participants' diagram comprehension ability, we used a Norwegian adaptation of a measure developed by Cromley et al. (2013). This measure included 10 items concerning the domain of geoscience, with each item consisting of a diagram including labels and a figure caption. As such, the verbal information included in the measure ranged from structure labels to explanatory captions. Taken together, the 10 items covered various areas within geoscience, such as oceanography, meteorology, hydrology, and thermochemistry. Each diagram was followed by a multiple-choice question with one correct answer and three distractors. This measure has been validated with high school students by Cromley and colleagues (Bergey et al., 2015; Cromley et al., 2013) and with college students by Van Meter and colleagues (Van Meter et al., 2017). For example, Van Meter et al. (2017) found that scores on this measure were positively associated with participants' learning from illustrated text about another topic (human physiology). To ensure the correctness of all the terminology used in the labels, captions, questions, and response alternatives, a preliminary Norwegian version of the measure was reviewed by a professor of geoscience at the University of Oslo who was not part of the project. This resulted in changes to only two Norwegian terms included in two of the items. Scoring was done by counting the number of correct responses (maximum score = 10). A reliability estimate of 0.74 has been obtained for scores on this measure when used with undergraduate students.

2.3. Procedure

Data were collected individually in one 60-min session in a quiet room at the university, with all materials administered by the first author. On arrival, participants were sequentially assigned to one of the four experimental conditions, that is, print/prompt ($n = 25$), print/no prompt ($n = 25$), digital/prompt ($n = 25$), and digital/no prompt ($n = 25$). First, all participants received a folder containing a demographic survey, the diagram comprehension measure, and the reading comprehension measure, and completed these tasks on paper in this order. When finished, the eye tracker was calibrated by using an A4 sized page with three points (two in the upper corners and one in the middle at the bottom). Participants then read the following instruction on paper: *You are now going to read a short illustrated expository text on the physiology of sexuality. Afterwards, you are going to write a brief report based on this illustrated text, in which you explain similarities and differences between the sexual responses of males and females*. Of note is that this task involved a comparison of the sexual response cycles of males and females as described in the document and required that participants integrate complementary textual and pictorial information. This was explicitly pointed out to participants randomly assigned to the diagram awareness prompt condition, who also read the following instruction: *Note that both the text and the illustration contain important information. Understanding this topic requires that you combine information from the text and the illustration by relating them to each other.*

After reading the instruction, all participants were presented with a blank page containing a small yellow square in the upper left corner, on which they were instructed to fixate. In this way, we ensured that all participants started reading at the same place. This page was presented to participants in their assigned reading medium (as was the calibration page described above). Participants randomly assigned to the print condition read the document on a book stand to ensure that the eye tracking glasses recorded all eye movements in their focal area. Eye movement recording started when participants had fixated the yellow square, after which the fixation page was removed from the book stand and participants started reading the illustrated text placed underneath it. Participants randomly assigned to the digital condition read the document as a PDF file on the desktop computer screen. After having fixated on the yellow square, participants clicked on an arrow button to remove the fixation page and get access to the illustrated text.

In all experimental conditions, participants were orally instructed to start reading the document as soon as it became visible to them and informed that they could spend maximum five minutes on the reading task. This time limit was based on pilot testing indicating that five minutes would allow all participants to read the document from beginning to end and also leave time for re-reading and studying the document more thoroughly. Still, the maximum reading time was intended to make participants experience a certain time pressure because prior research has indicated that effects of reading medium tend to be more pronounced when reading is time-constrained rather than self-paced (Delgado et al., 2018).

When participants indicated that they had finished studying the document or had reached the time limit of five minutes, they first completed the task-based intrinsic motivation inventory on paper. Then, they accessed a web based questionnaire by clicking on a Google Chrome window located on the taskbar of the desktop computer (also participants reading in print had a computer on their desk). This questionnaire contained the following writing task instruction: *Explain similarities and differences between male and females' sexual response cycles based on the illustrated text you just read. You can spend as much time as you like on this writing task. It is important that you express yourself as completely and elaborately as you can.* Under this instruction, participants wrote their report in a separate text entry box with no word limit. Participants could not re-access the illustrated text while writing their report. After they finished their report, they submitted it to a server by clicking on a "Send" button.

3. Results

3.1. Descriptive and correlational analyses

Table 1 includes descriptive information and zero-order correlations for all measured variables for the entire sample. The descriptive information indicated that all variables were approximately normally distributed and, thus, suitable for parametric statistical analyses. Moreover, the descriptive information included in Table 1 indicated that participants, on average, had relatively low diagram comprehension but reported relatively high intrinsic motivation for the reading task. As indicated by the integrative processing score, they also made a substantial number of transitions among complementary textual and pictorial parts of the document; yet, obtained only moderate scores with respect to integrated understanding of the document content. Still,

Table 1
Descriptive statistics and zero-order correlations for all measured variables for the entire sample ($n = 100$).

Variable	1	2	3	4	5
1. Task-based intrinsic motivation	–				
2. Reading comprehension	0.09	–			
3. Diagram comprehension	0.21*	0.34**	–		
4. Integrative processing	0.07	0.22*	0.17	–	
5. Integrated understanding	0.39**	0.23*	0.30**	0.31**	–
M	3.68	28.01	5.63	32.39	5.07
SD	0.70	6.52	1.79	15.20	2.76
Skewness	−0.16	−0.07	−0.52	0.69	−0.10

Note. $^*p < .05$, $^{**}p < .01$.

Table 2
Descriptive information for subgroups differing with respect to reading medium and instructional prompt.

	Print		Digital	
	Prompt (n = 25)	No prompt (n = 25)	Prompt (n = 25)	No prompt (n = 25)
Task-based intrinsic motivation	3.62 (0.68)	3.70 (0.79)	3.57 (0.62)	3.82 (0.71)
Reading comprehension	28.52 (5.54)	27.60 (6.71)	27.56 (7.66)	28.36 (6.32)
Diagram comprehension	5.84 (1.66)	5.40 (1.83)	5.76 (1.86)	5.52 (1.92)
Integrative processing	37.50 (17.35)	34.00 (14.81)	29.18 (13.90)	28.54 (13.49)
Integrated understanding	4.20 (2.61)	5.56 (2.66)	5.32 (2.95)	5.20 (2.77)

the zero-order correlations included in Table 1 showed that integrative processing was positively and statistically significantly correlated with participants' integrated understanding, as were all the individual difference measures (i.e., intrinsic motivation, reading comprehension, and diagram comprehension). Only the individual difference variable of reading comprehension was positively and statistically significantly correlated with integrative processing, however.

Table 2 shows descriptive information about the measured variables for the subgroups differing with respect to reading medium and instructional prompt. One-way analyses of variance using the four subgroups as the independent variable and the covariates (i.e., intrinsic motivation, reading comprehension, and diagram comprehension) as the dependent variables showed no statistically significant differences between the subgroups, with $F(3, 96) = 0.61$, $p = .61$, $\eta^2 = 0.018$, for intrinsic motivation; $F(3, 96) = 0.14$, $p = .93$, $\eta^2 = 0.004$, for reading comprehension; and $F(3, 96) = 0.32$, $p = .81$, $\eta^2 = 0.009$, for diagram comprehension.

3.2. Effects on integrative processing

To test our hypotheses regarding the effects of conditions on integrative processing, we performed a 2 × 2 between-subjects analysis of covariance (ANCOVA) with reading medium (print, digital) and instructional prompt (prompt, no prompt) as the independent variables and integrative processing as the dependent variable. Because intrinsic motivation and diagram comprehension were not correlated with integrative processing (see Table 1), only reading comprehension was included as a covariate in this analysis. Results of the evaluation of the assumptions for performing ANCOVA were satisfactory.

The main effect of reading medium (print: $M = 35.75$, $SE = 2.10$; digital: $M = 28.87$, $SE = 2.17$; $F(1, 90) = 5.22$, $p = .025$, $\eta_p^2 = 0.055$) was statistically significant. However, the main effect of instructional prompt (prompt: $M = 33.35$, $SE = 2.17$; no prompt: $M = 31.27$, $SE = 2.10$; $F(1, 90) = 0.47$, $p = .493$, $\eta_p^2 = 0.005$) was not statistically significant. There was also no statistically significant interaction between reading medium and instructional prompt, with $F(1, 90) = 0.96$, $p = .758$, $\eta_p^2 = 0.001$. The effect of the covariate (i.e., reading comprehension) was statistically significant, with $F(1, 90) = 4.94$, $p = .029$, $\eta_p^2 = 0.052$.

Thus, as predicted, participants who read on paper, as opposed to on the computer, displayed more integrative processing. However, the effect of reading medium on integrative processing was not moderated by the instructional prompt, with participants reading on the computer displaying less integrative processing regardless of prompt.

3.3. Effects on integrated understanding

Further, to test our hypotheses regarding the effects of conditions on integrated understanding of document content, we performed a 2 × 2 between-subjects ANCOVA with reading medium (print, digital) and instructional prompt (prompt, no prompt) as the independent variables and integrated understanding as the dependent variable. Covariates in this analysis were intrinsic motivation, reading comprehension, and diagram comprehension. Results of the evaluation of the assumptions for performing ANCOVA were satisfactory.

Neither reading medium (print: $M = 4.90$, $SE = 0.35$; digital: $M = 5.24$, $SE = 0.35$; $F(1, 93) = 0.48$, $p = .492$, $\eta_p^2 = 0.005$), nor instructional prompt (prompt: $M = 4.82$, $SE = 0.35$; no prompt: $M = 5.32$, $SE = 0.35$; $F(1, 93) = 1.03$, $p = .312$, $\eta_p^2 = 0.011$), had statistically significant main effects on integrated understanding. Also, there was no statistically significant interaction between reading medium and instructional prompt, with $F(1, 93) = 3.59$, $p = .061$, $\eta_p^2 = 0.037$. The effects of the covariates of intrinsic motivation, $F(1, 93) = 13.02$, $p < .001$, $\eta_p^2 = 0.123$, and diagram comprehension, $F(1, 93) = 4.14$, $p = .045$, $\eta_p^2 = 0.043$, but not the effect of reading comprehension, $F(1, 93) = 2.46$, $p = .120$, $\eta_p^2 = 0.026$, reached statistical significance. Thus, our hypotheses regarding main effects of reading medium and instructional prompt, as well as an interaction effect of reading medium with instructional prompt, on integrated understanding were not confirmed.[2]

3.4. Mediation analysis

Finally, we tested our prediction that participants' integrative processing would mediate the effects of reading a printed versus a digital document on their integrated understanding of the content. Of note is that this is possible although the *c* path (i.e., the effect of reading medium on integrated understanding) was not statistically significant (see Fig. 1), as would be required by the conventional causal steps approach (Baron & Kenny, 1986). However, this historically popular approach has been criticized because of reduced power due to the multiple statistical significance tests it requires (Preacher & Selig, 2012), and because it can be considered illogical to assess mediation without directly testing it via the *ab* path (see Fig. 1; e.g., Hayes, 2009). Because the bootstrapping procedure developed by Preacher and Hayes (2008) holds no assumption about the statistical significance of the *c* path, and because the pattern of relationships that we observed made it possible to test the indirect effect of medium condition on integrated understanding, we opted for the bootstrapping approach proposed by those authors in the current research. Specifically, as can be seen in Table 1, participants in the print condition performed more integrative processing when reading the document than did those in the digital condition. Also, there was a positive relationship between integrative processing and integrated understanding of the document content, with participants performing more cross-representational gaze transitions also more likely to display integrated understanding in their written products. This pattern made it possible to test the indirect effect of medium condition on comprehension performance via integrative

[2] We also performed a 2 × 2 between-subjects ANCOVA with the same independent variables and covariates, using an integrated understanding measure based on only the six idea units that required integration of textual and pictorial information (see Appendix B) as the dependent variable. The results were similar, with neither reading medium (print: $M = 3.50$, $SE = 0.28$; digital: $M = 3.68$, $SE = 0.28$; $F(1, 93) = 0.22$, $p = .639$, $\eta_p^2 = 0.002$), nor instructional prompt (prompt: $M = 3.28$, $SE = 0.28$; no prompt: $M = 3.90$, $SE = 0.28$; $F(1, 93) = 2.30$, $p = .113$, $\eta_p^2 = 0.024$), having statistically significant main effects on integrated understanding. Also, there was no statistically significant interaction between reading medium and instructional prompt, $F(1, 93) = 2.02$, $p = .159$, $\eta_p^2 = 0.021$. The effects of the covariates of intrinsic motivation, $F(1, 93) = 11.99$, $p = .001$, $\eta_p^2 = 0.114$, and diagram comprehension, $F(1, 93) = 3.96$, $p = .049$, $\eta_p^2 = 0.041$, but not the effect of reading comprehension, $F(1, 93) = 2.06$, $p = .155$, $\eta_p^2 = 0.022$, were statistically significant. The correlation (Pearson's r) between the integrated understanding measures based on six and nine idea units was 0.95, indicating that they captured the same construct.

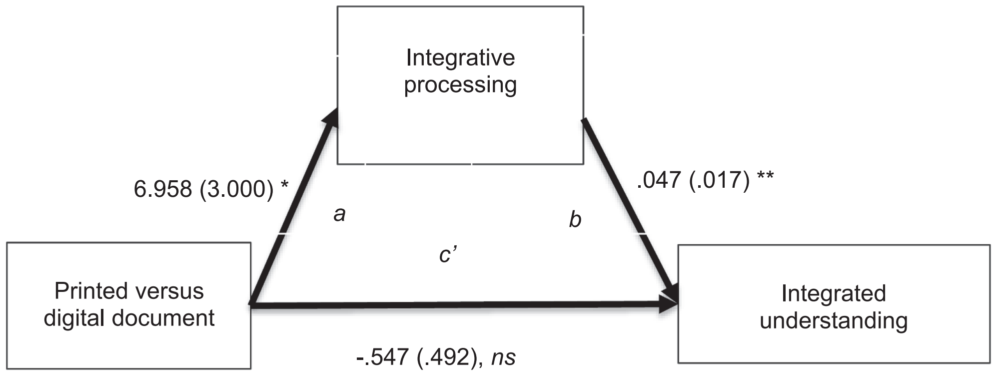

Fig. 1. Mediation model for the effect of medium condition (1 = print, 0 = digital) on integrated understanding with integrative processing as a mediator.

processing by means of the bootstrapping procedure.

Thus, we tested the effect of reading medium (printed document vs. digital document) on integrated understanding of the document content, using amount of integrative processing as a mediator and scores on task-based intrinsic motivation, reading comprehension, and diagram comprehension as covariates. We included all three individual difference measures as covariates because they were correlated with integrated understanding (see Table 1). Reading medium was coded 1 for print and 0 for digital. To test the indirect effect, we used a bootstrap estimation approach with 1000 samples (Preacher & Hayes, 2008). The resulting model explained a statistically significant portion of the variance, $R^2 = 0.29$, $F(5, 89) = 7.27$, $p < .0001$. There was a positive statistically significant effect of reading medium on integrative processing, $B = 6.958$, $SE = 3.000$, $p = .023$, as well as a positive statistically significant effect of integrative processing on integrated understanding, $B = 0.047$, $SE = 0.017$, $p = .006$.This means that, on average, participants reading on paper performed nearly seven transitions more that did participants reading on a computer, and for each additional transition, there was a 0.05 point increase in integrated understanding. As hypothesized, there was also a positive statistically significant indirect effect of medium condition on integrated understanding via integrative processing, with an estimate of 0.33 ($CI_{95\%}$: 0.03–0.85). This means that as a consequence of reading on paper, as opposed to on a computer, there was a 0.33 point increase in integrated understanding (approx. 8.4% of a standard deviation) due to the mediation effect. The direct effect of reading medium on integrated understanding remained statistically non-significant, $B = -0.547$, $SE = 0.492$, $p = .270$. Finally, the covariates of reading comprehension ($B = 0.045$, $SE = 0.040$, $p = .260$) and diagram comprehension ($B = 0.222$, $SE = 0.143$, $p = .125$) were not statistically significant predictors. However, task-based intrinsic motivation was a statistically significant positive predictor, with $B = 1.324$, $SE = 0.362$, $p < .001$.[3]

4. Discussion

This study is the first experimental investigation of the effects of reading medium on processing and comprehension of the same materials across mediums in a multimedia learning context. Moreover, it is unique in harnessing eye tracking methodology to directly test the shallowing hypothesis used to explain why reading in print more often than not results in better comprehension performance than reading digitally (Annisette & Lafreniere, 2017; Delgado et al., 2018). Although there were no main effect of reading medium on comprehension performance in the present study, it was found that participants reading in print displayed more integrative processing of textual and pictorial information than participants reading digitally, and that such cross-representational processing, in turn, predicted their integrated understanding of the multimedia content. Thus, consistent with the shallowing hypothesis, we found evidence of more shallow or superficial information processing in the digital than in the print reading context (Annisette & Lafreniere, 2017), objectively measured by the number of cross-representational gaze transitions performed when reading the illustrated text (Mason et al., 2017; Stalbovs et al., 2015). Consistent with the cognitive theory of multimedia learning (Mayer, 2014) and prior research on the relationship between such generative, integrative processing and multimedia learning (Alemdag & Cagiltay, 2018), more integrative processing was associated with more complete, integrated understanding of the topic in question.

Although consistent with the cognitive theory of multimedia learning with respect to its emphasis on the role of generative, integrative processing in constructing an integrated mental representation from verbal and pictorial information (Mayer, 2014), the findings of the current study seem to qualify this theory by showing that reading medium matters for this most crucial step in multimedia learning. As noted previously, Mayer (2003) has documented that the principles of multimedia learning (e.g., the spatial and temporal contiguity principles) operate similarly across print and digital mediums. Based on such findings, it seems premature, however, to draw the conclusion that examining the effects of medium per se is not a productive research strategy (Mayer, 2003). Rather, the current study indicates that the reading medium per se may influence essential processes of multimedia learning in hitherto unknown ways.

Of note is also that the findings of the current study extends prior eye tracking research on the relationship between integrative processing and multimedia learning. This is because this line of research has not included dependent measures directly targeting integrated understanding of textual and pictorial information, and therefore not provided direct evidence that integrative processing as indicated by participants' eye movements is associated with an integrated understanding of the multimedia (i.e., textual and pictorial) content (Alemdag & Cagiltay, 2018). In part, this may be due to the fact that most of this research has used multimedia materials in the form of text and pictures that contain the same information but represent it in different ways, rather than in the form of text and pictures that contain different (i.e., complementary) information that has to be combined in order to achieve a complete understanding of the document content (e.g., Mason et al., 2017; Mason et al., 2013a; Mason et al., 2015b). In keeping with Mayer's (2014) theory, the current study uniquely extended prior eye tracking research on multimedia learning by linking integrative processing data based on eye tracking to the construction of an understanding that integrated information across textual and pictorial representations.

There may be several reasons why there was no reading medium effect on integrated understanding despite the mediation effect described above. In addition to the mediation effect being quite small, this

[3] We also performed the mediation analysis with 10,000 instead of 1000 bootstrap samples. No effects changed as a result of this incease in samples, however.

study was distinguished from other studies in this area by using a longer writing task to measure comprehension performance. In contrast, the vast majority of previous studies investigating the effect of reading medium on comprehension (for reviews, see Clinton, 2019; Delgado et al., 2018) used multiple-choice and question-answering tasks. Thus, one possibility is that asking participants to produce a longer, coherent written product might have increased post-reading reflection and performance regardless of the reading medium.

Also, the fact that there was no total effect of reading medium on integrated understanding despite the mediation effect might suggest that there were other mediation processes working in the opposite direction, that is, in the favor of the digital condition. However, from a theoretical perspective, such processed are difficult to discern. Thus, while the interactivity of digital books might be associated with reading motivation and enjoyment, although the evidence is inconclusive (e.g., Grimshaw, Dungsworth, McKnight, & Morris, 2007), there is, to the best of our knowledge, no prior study proposing a particular mechanism that could produce comprehension advantages for non-interactive digital documents over printed documents. In the current study, there was also no evidence for differences with respect to motivation and engagement between the two reading medium conditions in the favor of digital reading.[4]

However, another mechanism that might have worked in favor of the digital condition is related to the procedure of the present study, specifically to the consistency between the mediums used for reading and writing. Thus, participants in the digital condition read the text on a desktop computer and subsequently performed the writing task on the same computer, whereas participants in the print condition read the illustrated text on paper but then switched medium and performed the writing task on a desktop computer.[5] Of note is that this procedure has not been common in previous research. For example, the meta-analysis by Delgado et al. (2018) included only one study in which testing was done digitally regardless of reading medium. The possibility that the consistency of the medium across reading and writing may have been advantageous for the digital condition is consistent with the view that different mediums for reading and testing may increase the cognitive load for learners (e.g., Mayes, Sims, & Koonce, 2001; Mangen, Walgermo, & Brønnick, 2013; Noyes & Garland, 2008). Needless to say, the extent to which the comprehension performance measure and the consistency between the reading and writing (i.e., testing) mediums might influence reading medium effects should be investigated in future experimental work.

We also cannot entirely rule out the possibility that the lack of a reading medium effect on integrated understanding may be associated with a floor effect because participants obtained only moderate scores on the latter measure. Larger samples yielding more statistical power may also be needed to detect the relatively small effects of reading medium on comprehension performance that can be expected based on meta-analytic studies (Clinton, 2019; Delgado et al., 2018).

Although we also expected main effects of a diagram awareness prompt on both integrative processing and integrated understanding, as well as entertained the possibility that the main effects of reading medium on those variables might be moderated by a diagram awareness prompt (Van Meter et al., 2017), no such main or interaction effects were observed in the current study. Rather, participants reading the illustrated text on the computer displayed less integrative processing regardless of the prompt. There are several possible reasons for this lack of effects. For example, one possibility is that signaling the importance of both types of representations and their relationship in this way was redundant given the participants' vast experience reading illustrated text. Another possibility is, however, that the instructional prompt that we used in this study merely signaled to students what was important to do but not how and when they should do it (Stalbovs et al., 2015). In contrast, Van Meter et al. (2017) more explicitly instructed students about how text and diagram should be linked by means of an extensive tutorial video, with students also practicing how to respond to the prompt before starting on the learning task. Moreover, in the Van Meter et al. (2017) study, students were given the instructional prompt several times during task completion.

A viable alternative to using instructional prompts may be to use implementation intentions in the form of specific if-then plans (e.g., if I have read a paragraph referring to a figure, then I will study the figure to combine information from the text and the figure) to improve learners' integrative processing when reading in a digital context (Stalbovs et al., 2015). Moving beyond both instructional prompts and implementation intentions, direct teaching to improve students' processing of pictorial representations (Bergey et al., 2015; Cromley et al., 2013, 2016) or modeling integrative processing of textual and pictorial representations (Mason et al., 2017; Mason et al., 2015a, 2016) may be needed in digital contexts to reduce reading medium effects on integrative processing of multimedia content. This is an area for future research on the effects of reading medium on multimedia learning, however.

Among the individual difference variables that we included as potential covariates in the current study, participants' basic reading comprehension skills uniquely predicted their integrative processing, and task-based intrinsic motivation and diagram comprehension uniquely predicted their integrated understanding. Moreover, intrinsic motivation was a unique predictor in the mediation analysis that we conducted. These findings highlight the importance of controlling for these individual difference variables in future research on the effects of reading medium on the processing and comprehension of illustrated text. Although our data regarding the relationships between the individual difference variables and the processing and comprehension variables were merely correlational, the fact that the individual difference variables predicted integrative processing and integrated understanding independently of reading medium also may suggest that they are important contributors to multimedia learning regardless of the medium. In particular, motivational and emotional variables have thus far been underfocused in theory on multimedia learning (Mayer, 2019) as well as in prior eye tracking research in this area (Alemdag & Cagiltay, 2018). In this study, we measured participants' intrinsic motivation immediately after reading the document because we wanted to capture their current, task-based rather than habitual intrinsic motivation (Schiefele et al., 2012). It might therefore be argued that intrinsic motivation should be considered a dependent variable rather than an independent (or control) variable in this study. However, given that there were no indications in our data that the conditions differed with respect to intrinsic motivation, it seems unlikely that this variable was influenced by the experimental manipulations. Of note is also that measuring text-based or situational intrinsic motivation or interest by asking learners to rate themselves immediately after or during task performance has been validated in a number of prior studies (e.g., Ainley & Patrick, 2006; Bråten et al., 2014, 2017; Yaros, 2006). Still, more studies of the effects of motivational and emotional variables on integrative processing and integrated understanding of multimedia materials are highly needed, also using other methodologies to capture such variables than the one we used in the current study. Given that

[4] To explore this possibility, we compared the reading medium conditions with respect to self-reported intrinsic motivation and two indicators of behavioral engagement: total fixation time on the text and total fixation time on the diagram. All these variables were positively correlated with integrated understanding (intrinsic motivation: $r = 0.39$, $p < .001$; total fixation time on the text: $r = 0.22$, $p = .03$; total fixation time on the diagram: $r = 0.31$, $p = .01$). However, there were no differences between the reading medium conditions with respect to intrinsic reading motivation, $t(98) = -0.23$, $p = .82$, total fixation time on the text, $t(93) = -1.01$, $p = .32$, or total fixation time on the diagram, $t(93) = -0.75$, $p = .47$.

[5] The main reason we used this procedure was that students at this level typically perform their writing tasks on a computer and that having them write on paper therefore might reduce the ecological validity of our findings.

several other individual difference variables, for example, prior knowledge and metacognitive awareness (McNamara & Magliano, 2009a, 2009b), as well as beliefs about the topic in question and beliefs about the nature of knowledge and the process of knowing (i.e., epistemic beliefs; Bråten & Strømsø, 2020), may also influence the building of coherent mental representations from diverse information sources, additional variables should be included as covariates in future research in this area.

This study extended prior research on the effects of reading medium on text comprehension to a multimedia learning context and demonstrated the applicability of the shallowing hypothesis to this context. Still, there are aspects of the shallowing hypothesis that were not addressed by our data and that need further theoretical and empirical clarification. For example, this concerns the precise nature of the mechanism by which reading in digital environments lead to more shallow information processing, whether there are differences among digital environments in this regard, and whether there are particular individual and contextual factors that facilitate (or constrain) this development.

Another issue that needs further clarification is whether there actually are qualitative differences in learners' integrative processing when reading in print versus digitally. While the difference in cross-representational gaze transitions that we observed may be interpreted as indicating a difference with respect to the depth of information processing (Mason et al., 2013a; Mason et al., 2015b; Mayer, 2014), the extent to which there are qualitative differences across the reading medium conditions cannot be directly addressed by the eye movement data. This means that the possibility that participants in the print condition simply invested more effort at the same level of depth (i.e., did more of the same) cannot be entirely ruled out at this point. Therefore, other methodologies for collecting process data, such as concurrent verbal protocols (Ericsson & Simon, 1993), may profitably be used to further test the shallowing hypothesis in future investigations.

Such process data might also throw light on the issue of whether there may be other mediation processes that work in the favor of digital reading than those we explored in the current research, and that therefore may neutralize or counteract positive effects of printed materials mediated through integrative processing. As noted above, systematically varying the outcome measures and the consistency between the reading and testing mediums may also throw light on the circumstances for reading medium effects (or the lack of such effects).

Needless to say, future investigations also need to probe the generalizability of our findings by including other populations, other topics, other types of relationships between the textual and pictorial representations, and more extensive learning materials, such as longer texts including a number of illustrations. In addition, increasing the ecological validity by collecting data in authentic classroom settings and comparing processing and comprehension of multimedia content across different digital devices (e.g., computers, tablets, and smartphones) may represent productive lines of future research in this area.

Despite the need for much further theoretical and empirical work, we maintain that our study provides new insights into medium effects on the process of reading. Moreover, these insights may have educational as well as theoretical implications. On the one hand, they may dampen some policy makers' and educators' unreserved enthusiasm for classrooms in which digital learning is essentially replacing learning with and from printed materials. On the other, they may encourage educators to find ways to counteract students' tendencies to pass more lightly over information presented in digital environments. Of special concern are transitions to digital contexts for conducting assessments in school, including formal, high stakes assessments. In such contexts, most students are likely to experience considerable time pressure, which may exacerbate potentially detrimental effects of reading digitally. In our view, a stronger research base is needed for making decisions regarding the medium for instruction as well as assessment in school. Hopefully, this study will be conceived as a valuable building block of this research base.

Appendix A. English version of the illustrated text

forskning.no
Research reporter Anniken Hauge
Published November 27th, 2018

The physiology of sexuality

Sex is often described as a drive with biological reproduction as its goal, but in reality people also have sex for pleasure. The desire to have sex is influenced by sex hormones. Both in males and females, androgens (male sex hormones) and not estrogens (female sex hormones) influence sexual desire the most.

Much of what we know about human sexual reactions today originates from a classic study conducted by the American researchers William Masters and Virginia Johnson more than 50 years ago. This study was reported in the book *Human Sexual Response,* which they published in 1966.

In this book, Masters and Johnson described the sexual response cycle by means of four stages of physiological changes that occur during sexual activity. These four phases are called the excitement phase, the plateau phase, the orgasm phase, and the resolution phase. According to Master and Johnson, the sexual response cycle in females is varied and may have alternative patterns (see Figure 1).

In males arousal builds in the plateau phase until the muscle tension in the body becomes so strong that it triggers an orgasm. The orgasm is then followed by a resolution phase in which the excitement decreases rapidly and the genital organ returns to its normal condition. During the resolution phase, directly after the orgasm, males experience a so called refractory period, during which they are temporarily incapable of having another orgasm.

According to Norwegian Health Informatics, 24% of Norwegian women report that they for a longer period of time have a sexual response cycle corresponding to pattern B. Moreover, Masters and Johnson reported that relatively few women experience profile A.

Of course, sex concerns more than sex hormones and physiological reactions. Psychological, social, and cultural factors contribute to shaping human sexuality. In brief, sexuality, in all its diversity, is a central part of being human in the world throughout all stages of life.

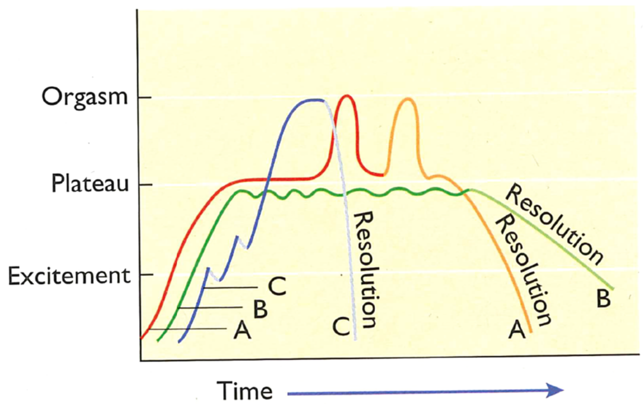

Figure 1. Sexual response cycle in females. Profile A shows one or more orgasms followed by resolution, profile B shows a plateau phase with no orgasm, and profile C shows an orgasm with no preceding plateau phase.

Appendix B. Coding system for scoring the written responses

Idea unit 1: *Androgens (male sex hormones) and not estrogens (female sex hormones) influence the sexual desire the most.*
Concerns similarity, based on textual information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	They describe that females and males are driven by different hormones (estrogen and androgen) and that these influence the body differently and thus also the sexual responses.
1	Participants correctly described the influence of male and female sex hormones.	Sexual arousal mostly comes from the male sex hormones, and not the female sex hormones estrogen.

Idea unit 2: *Males and females experience four phases during sexual activity.*
Concerns similarity, based on textual information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	In a study of different processes in sexual activity, they used terms like e.g. resolution, orgasm.
1	Participants correctly mentioned a least three of the four phases.	Common for both sexes is that they all experience sexual response in phases, which means there are different stages in the sexual response. These phases are excitement, plateau, orgasm, and resolution.

Idea unit 3: *Females may experience multiple successive orgasms.*
Concerns difference, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	For males during intercourse it was reported that they could have up to three orgasms, with the third making them totally exhausted.
1	Participants correctly described that females may experience multiple successive orgasms.	They [females] can have an excitement phase that shifts to a plateau phase in which they then can achieve one or more orgasms before they get relaxed.
2	Participants correctly compared females to males.	Females have, for example, the possibility to experience two orgasms before a resolution phase. Males, on the other hand, always move directly to the resolution phase after ejaculation.

Idea unit 4: *Females may not experience orgasm.*
Concerns difference, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	From this, I got to know that males more easily than females enter the excitement phase and experience an orgasm.
1	Participants correctly described that females may not experience orgasm.	Females may experience different phases […]: Excitement and a subsequent plateau phase without orgasm before entering the resolution phase.
2	Participants correctly compared females to males.	Thus, from the text one can draw the inference that for males, sex will more or less always end with an orgasm, whereas many females express that for them, this is not always the case.

Idea number 5: *Females may not experience any plateau phase.*
Concerns difference, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	Both males and females experience satisfaction but males have more build-up to it than ladies.
1	Participants correctly described that females may not experience any plateau phase.	A third sexual response in females was to skip the plateau phase and move directly to the orgasm phase.
2	Participants correctly compared females to males.	It was apparent that males normally remained in the plateau phase until they had an orgasm […]. This was different for females, who might […] skip the plateau phase and move directly to orgasm.

Idea unit 6: *Males experience a refractory period.*
Concerns difference, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	After the orgasm, the resolution phase begins […]. Still, it is easy for males to return to the excitation phase.
1	Participants correctly described the refractory period experienced by males.	Males experience an increasing degree of arousal until the muscles tense, followed by climax. Then, a period of resolution follows in which males are incapable of achieving a new orgasm.
2	Participants correctly compared males to females.	Males, in contrast to females, experience what is called a “refractory period,” which hinders males in obtaining an orgasm during a certain time span, females, on the other hand, do not have this problem.

Idea unit 7: *Females experience a varied sexual response cycle.*
Concerns difference, based on textual information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	Males usually follow all of these stages, whereas in females this is more unclear.
1	Participants correctly described that females experience a more varied sexual response cycle	Females experience larger variation in their sexual responses than males […].

Idea unit 8: *24% of Norwegian females report that may have a sexual response cycle corresponding to pattern B.*
Concerns elaboration of female pattern B, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	The text referred to a report which said that quite a few females (more than 50%) most of the time experienced what is called a plateau during sexual intercourse.
1	Participants correctly described that 24% of females may experience pattern B.	Studies show that 24% of females respond that they usually have a sexual response similar to profile B.
2	Participants correctly elaborated upon their description of female pattern B.	Center for Norwegian Health Informatics claimed that 24% of Norwegian females are categorized as B. Here one starts with excitement, but remains at plateau without orgasm, before reaching the resolution stage.

Idea unit 9: *Relatively few females experience pattern A.*
Concerns elaboration of female pattern A, based on textual and pictorial information.

Score	Definition	Example
0	Participants gave no response or described irrelevant or incorrect information.	According to Norwegian Health Informatics approx. 28 percent of females have experienced the first variant, i.e. graph A.
1	Participants correctly described that relatively few females experience pattern A.	Masters and Johnson found that few females had the sexual response illustrated by A.
2	Participants correctly elaborated upon their description of female pattern A.	According to the researchers, few females experience multiple successive orgasms, where excitement increases until orgasm is achieved, and then have another orgasm before the resolution phase occur.

Note. In translating the examples used in this table, we tried to retain participants’ original expressions rather than transforming them into (more) correct grammar.

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