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An Eye Tracking Based Investigation of Multimedia Learning Design in Science Education Textbooks

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ABSTRACT: This study investigated the effects of multimedia learning and visual design in a 6th grade science textbook on students' studying processes. This was accomplished by using eye tracking technology and by applying multimedia learning design and visual design principles to science textbooks. Eye tracking based testing was employed to evaluate the effects of multimedia learning and visual design principles on students' studying process as they interacted with the revised textbook chapter. The results revealed that the revised cell biology chapter facilitated answering achievement test questions and helped attentional focus on relevant images, as well as more successful integration of text and images during students' studying processes. These research findings can be used in the design process to develop science textbooks based on learner needs. The research also provides guidelines for designing similar multimedia learning materials. Thus, the research results may contribute both theoretical and practical implications for the multimedia learning design of science textbooks.

Keywords: Multimedia learning design, Visual design, Eye tracking, Textbook

1. Introduction

Textbooks are common learning materials in schools all around the world. Content, pedagogy, and visual design are common criteria categories used for textbook evaluation in the literature (Lemmer et al., 2008; Maun, 2006; Vinisha & Ramadas, 2013). There are three usual types of textbook evaluation studies including (1) survey method, (2) textbook analysis, and (3) experimental evaluation (Mikk, 2002). Qualitative research methods were also used to examine the quality of textbooks (Maun, 2006; Lemmer et al., 2008). All the evaluation methods for textbooks are helpful in investigating the instructional value of a textbook. However, studies generally do not examine students' learning experience directly while they are interacting with textbooks.

The visuals, and the integration of text and visuals in science textbooks were examined in textbook analysis studies. These studies focused on the criteria such as the type of visuals used, the proximity of text and visuals, and the integration of text and visuals (Slough et al., 2010; Vinisha & Ramadas, 2013). The integration of text and pictures and the visual design of the textbook can affect learning (Mayer, 2014; McCrudden & Rapp, 2015) so principles including Cognitive Theory of Multimedia Learning (CTML), Cognitive Load Theory, message design and visual design can be useful in textbook evaluation. Nevertheless, there is a gap for examining multimedia learning and textbook design from an instructional design perspective in the literature (Cheng et al., 2015; Mayer et al., 1996; Mayer et al., 1995; Peterson, 2016).

There are numerous studies related to multimedia learning and eye tracking that examined several principles such as multimedia, signaling, prior knowledge etc. of CTML for the integration of text and visuals in learning materials (Boucheix & Lowe, 2010; Jarodzka et al., 2010; Johnson & Mayer, 2012; Mason et al., 2013; Molina et al., 2018; Ozcelik et al., 2010; Schneider et al., 2018). However, there is limited research examining multimedia learning by using eye tracking with younger learners (Mason et al., 2013; Molina et al., 2018; Yang et al., 2018). Most studies were conducted with university level students rather than target learner groups and learning materials included very concise visuals in Mayer's studies as well as short texts in materials used for other studies (Jarodzka et al., 2017). Therefore, it is important to investigate different multimedia learning design principles at once in diverse materials with the target learner groups (Jarodzka et al., 2017). Moreover, there is still a paucity of research examining the multimedia learning design of textbooks, and existing research examines learning outcomes and applies experimental methods (Cheng et al., 2015; Mayer et al., 1996). Thus, there is a need in the literature to investigate multimedia learning textbook design with target level learners by applying several instructional design principles of the CTML at once.

This study investigated the evaluation process of a 6th grade science textbook used in public schools as a multimedia learning material. This was accomplished using eye tracking and by synthesizing the perspectives of different participant groups (authors, graphical designer, students, and teachers). Multimedia learning design and visual design principles were also utilized to extend these perspectives based on the literature. The purposes of this study are to (1) examine multimedia learning design and the visual design of 6th grade science textbooks by using eye tracking methodology, and to (2) generate a guideline with several principles for evaluating the design of science textbooks.

2. Literature review

2.1. Textbook evaluation, multimedia learning, and visual design

In the literature, there are several studies evaluating textbooks through different research methods (e.g., Alpan, 2004; Karadağ et al., 2013; Keser, 2004; Lemmer et al., 2008; Maun, 2006; Mikk, 2002; Özay & Hasenekoğlu, 2007; Şahin, 2012; Uçar & Özerbaş, 2016; Vinisha & Ramadas, 2013). Survey studies are easy and valuable for revealing various criteria for judging the quality of a textbook from different sources such as authors, teachers, students, etc. However, different people value different criteria for evaluating textbooks (Mikk, 2002; Özdemir, 2007).

Textbook analyses examine various characteristics of textbooks based on strict criteria, using qualitative analytical methods such as content analysis, discourse analysis etc. (Abd-El-Khalicket al., 2017; Bierema et al., 2017; Mikk, 2002; Sharma & Buxton, 2015). Several characteristics of textbooks related to visual design including the type and the quality of the graphical or visual representations, the integration of visual representations with text (Gkitzia et al., 2011; Slough et al., 2010; Slough & McTigue, 2013; Vinisha & Ramadas, 2013), and changes in graphical representations in time (Lee, 2010) were explored by using textbook analysis. However, textbooks analysis has limitations such as difficulty in setting rules to decide all the important characteristics to be counted and the validity of collected data during the evaluation process (Mikk, 2002).

The literature shows that different research methods are helpful for examining different aspects of textbooks in evaluation processes. However, these methodologies do not examine the textbook design and development process and are mostly conducted after textbooks are published. Thus, there is a need to explore the textbook design and development process from an instructional design perspective. The criteria for textbook evaluation consist of various sub-criteria related to content, pedagogy, message design, visual design, and general features. For example, Young and Reigeluth (1988) emphasize the criteria for subject-matter content, social content, readability, and instructional design. Similar to general textbook evaluation, there are various criteria for evaluating science textbooks depending on different perspectives (Bösterli, 2015; Devetak & Vogrinc, 2013; Khine, 2013). For example, Bösterli (2015) developed a checklist including two different types of criteria/standard categories: set weighted standards and variable weighted standards. Previously, Devetak and Vogrinc (2013) defined three main criteria categories: general, textual, and pictorial.

The textbook analysis studies examining the visuals and the integration of text and visuals in science textbooks focused on the criteria such as the type of visuals used, the proximity of text and visuals, and the integration of text and visuals (Slough et al., 2010; Vinisha & Ramadas, 2013). However, none of the studies examined all the principles of visual design or message design in science textbooks using a holistic approach. The results of previous research showed that unrelated or decorative visuals and weak text-visual integration are common issues with science textbooks (Lee, 2010; Slough et al., 2010; Vinisha & Ramadas, 2013), and extraneous representations in textbooks remain an issue despite a widespread emphasis on using visuals which represent the learning content in the literature (Lee, 2010; Mayer, 2014).

Aside from research on visuals and the visual design of textbooks, there is a gap for examining multimedia learning textbook design from an instructional design perspective (Cheng et al., 2015; Mayer et al., 1996; Mayer et al., 1995; Peterson, 2016). A generative theory of textbook design was introduced supporting the use of annotated illustrations in science texts in the literature. The annotated illustrations exemplify the signaling principle of CTML, helping students' selection process of relevant words and relevant images. The results of other studies revealed that utilizing multimedia learning design in textbooks improves learning outcomes (Cheng et al., 2015; Mayer et al., 1996; Peterson, 2016).

The results of previous studies indicate that all the evaluation methods and criteria for textbooks and printed materials are helpful in investigating the instructional value of textbooks or other materials. However, there is an emphasis on a few common aspects of visual design and multimedia learning including the type of visuals used, the proximity of text and visuals, and the integration of text and visuals in the evaluation criteria (Cheng et al., 2015; Lee, 2010; Mayer et al., 1996; Mayer et al., 1995; Peterson, 2016; Slough et al., 2010; Slough & McTigue, 2013; Vinisha & Ramadas, 2013). A limited amount of research examines the visual design of textbooks holistically (Alpan, 2004). None of the other studies examined multimedia learning and visual design at once, holistically, nor did they investigate all the appropriate principles of multimedia learning and visual design for science textbooks separately (Cheng et al., 2015; Lee, 2010; Mayer et al., 1996; Mayer et al., 1995; Peterson, 2016; Slough et al., 2010; Slough & McTigue, 2013; Vinisha & Ramadas, 2013). Furthermore, the studies did not investigate students' learning or studying experience directly while they are studying with the textbooks. Thus, there is a need in the literature to investigate the design and development process of science textbooks holistically, utilizing multimedia learning and visual design principles.

2.2. Eye tracking, multimedia learning design and visual design

Eye tracking technology is a unique way to evaluate design principles in the CTML. There are numerous studies related to multimedia learning and eye tracking in the literature that examined several principles such as multimedia, signaling, prior knowledge etc. of the CTML for the integration of text and visuals in learning materials (Boucheix & Lowe, 2010; Jarodzka et al., 2010; Johnson & Mayer, 2012; Mason et al., 2013; Molina et al., 2018; Ozcelik et al., 2010; Schneider et al., 2018). Researchers investigated learning outcomes using several principles of multimedia learning such as signaling (e.g., Boucheix & Lowe, 2010; de Koning et al., 2010; Ozcelik et al.., 2010), prior knowledge (e.g., Canham & Hegarty, 2010; Jarodzka et al., 2010), the modality effect and the effect of pacing on learner's attention (e.g., Meyer et al., 2010; Schmidth-Weigand et al., 2010), color coding (e.g., Ozcelik, et al., 2009), and spatial contiguity (e.g., Johnson &Mayer, 2012). Review results from eye tracking studies in science learning suggest designing digital learning materials for science education based on multimedia learning design principles (Yang et al., 2018). Eye tracking methodology may provide educational researchers an opportunity to link learning outcomes and cognitive processes, and this methodology also helps to evaluate learning materials and review the design principles in learning environments. It is important to investigate different multimedia learning design principles at once in diverse materials with the target learner groups (Jarodzka et al., 2017).

3. Methods

This study employed a design-based research (DBR) model to examine multimedia learning and the visual design of a 6th grade science textbook through eye tracking. DBR was used in this study because designing multimedia learning material requires iterative analysis, design, development, and redesign (McKenney & Reeves, 2013).

3.1. The science textbook

The literature suggests that multimedia learning design promotes learning when applied to science textbook design (Cheng et al., 2015; Mayer et al., 1996). Of particular interest are research on issues related to students' understanding of cell biology (Vijapurkar et al., 2014). Consequently, a cell biology chapter in a 6th grade science textbook was selected to investigate this issue further. In the previous phase of DBR, the multimedia learning and visual design of a cell biology chapter was evaluated and several issues with the chapter and students' needs were exposed. The issues and students' needs were irrelevant pictures, unclear directions, inappropriate use of color, number of visuals, alignment issues, image size, unclear images, inconsistent design, quality of paper/printing, text design, complex pictures, image quality, inappropriate use of image shape, imbalanced design, not motivating, inappropriate for learner level, misconception, inappropriate for individual differences, disconnected from daily life. In this phase, the issues were solved, and the cell biology chapter was revised using several principles of multimedia learning design (multimedia, coherence, segmenting, signaling, personalization, pre-training, and spatial contiguity), visual design (accurate design, alignment, aesthetic proportion-balance, clarity, color, consistency, harmony, image, simplicity, unity), and emotional design.

3.2. Participants

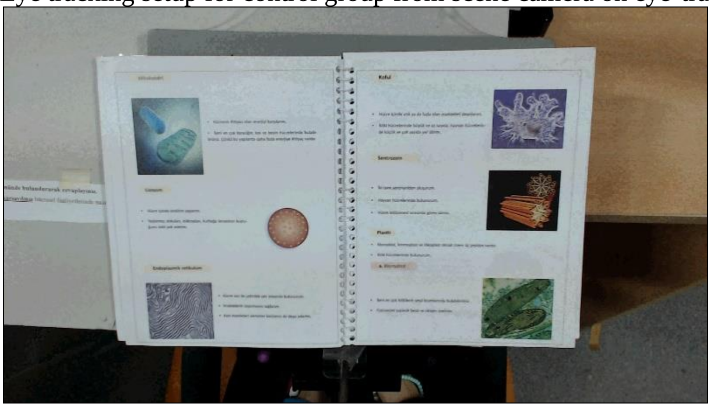
The selection criteria were that participants (1) should be 5th grade middle school students (2) should have little knowledge/understanding of the topic selected, (3) should show good performance in science class, (4) should not wear eyeglasses. Eighty students were selected as participants from one middle school based on their school cumulatives and science grades. It was also critical to select students known to be good in science and successful at school because their reading comprehension levels were assumed to be higher than other students, allowing them to learn a new science topic and allowing researchers to control the difference in reading comprehension levels in different groups of learners. There is a correlation between reading comprehension and science achievement in the literature (Cromley et al., 2010). Participants should also have little knowledge/understanding of cell biology, since their learning experience was examined. Eye tracking sessions were conducted with 60 participants (26 boys, 34 girls) because they were available to participate the study after dealing with several issues such as parental consent etc. There were two groups and participants were assigned to the groups by using simple random grouping method. Thirty students participated in one group, while another thirty students participated in the other group. Their ages were between 9 and 12 years.

3.3. Eye tracking setup

A Tobii X2-60 mobile eye-tracker and Tobii mobile eye-tracker stand were used to conduct the eye tracking test in this study (see Figure 1). Earlier to the session, a demographic survey and a ten-minute prior knowledge test including seven questions about cell biology basics were administrated to each participant. Subsequently, each participant underwent a brief orientation session during the eye tracking session. Participants could have a "practice" session before the "study" eye tracking session began. The eye tracking session began immediately after calibration of the eye-tracker. Participants answered seven achievement test questions identical to those in the prior knowledge test.

Figure 1. Eye tracking setup

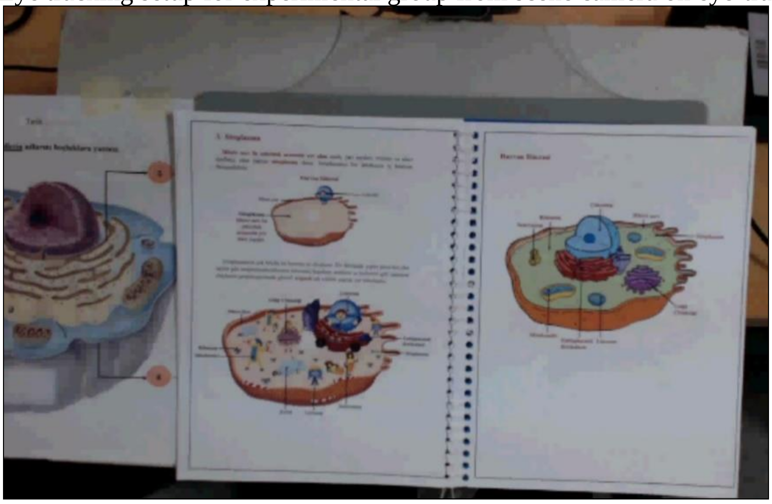
Figure 2. Eye tracking setup for control group from scene camera on eye-tracker stand



Participants studied for the achievement test questions by reading the textbook individually for an average of 40 minutes. First, they studied cell biology topics by themselves while their eye-movements were recording. Then, each question on a separate sheet of paper was presented and the researcher asked participants to answer these questions one at a time. Participants tried to complete the achievement test using a printed copy of the cell biology chapter.

Participants in one group used the unrevised version of the cell biology chapter in the textbook (see Figure 2) and the second group used the revised version of the same chapter (see Figure 3).

Figure 3. Eye tracking setup for experimental group from scene camera on eye-tracker stand



3.4. Data sources and analysis

Eye movements and a voice recording of the eye tracking sessions, as well as the achievement test (r = .92), the prior knowledge test, and the student demographic survey were among the data sources for the study. The prior knowledge test was evaluated by experts for validity check. Areas of Interest (AOI) were created to calculate eye tracking data on relevant texts and relevant images in previously created scenes. Eye tracking measures including fixation duration, total fixation duration, proportion of fixations, visit duration, and visit count for relevant images and relevant texts were calculated.

Beside those eye tracking measures, transitions (integrative transitions, text-to-diagram transitions, and corresponding transitions) were counted in the eye tracking data. Achievement test performance and eye tracking data were analyzed using descriptive statistics and one-way ANOVA.

Additionally, the researcher used a standard test protocol during eye-tracking sessions and followed the protocol step by step for both groups.

4. Results

4.1. Achievement test results

Results revealed that both groups were similar to each other in terms of grades in science class, $F(1, 58) = .428$, $p = .51$ and in school as measured cumulatively $F(1, 58) = 3.97$, $p = .05$. Prior knowledge results revealed that the participants did not have much knowledge on cell biology topics, although some of them (3 participants in the control group and seven of them in the experimental group) already knew the definition of “cell” and some basic concepts.

A normality assumption was tested, and the results satisfied the assumption for the unrevised chapter group, but the results seemed not to satisfy the normality assumption for the revised chapter group. (Das & Imon, 2016; Field, 2016; Thode, 2002). However, ANOVA is robust to violations of the normality assumption, so it was used to compare means for achievement test scores in the two groups (Field, 2016). For the homogeneity of variance assumption, the results of Levene’s test showed that the assumption was not satisfied, $F(1, 58) = 29.98$, $p = .00$. But the sample sizes for both groups were equal and p value was decreased from .05 to .01 to conduct one-way ANOVA for these measures, as well as conducting Welch and Brown-Forsythe corrections (p = .00) (Field, 2016).

Table 1. One-Way ANOVA summary table for the effects of multimedia learning design on achievement test scores

Achievement test scores	*df*	*SS*	*MS*	*F*	*p*	η^2
Between-group	1	5096.81	5096.81	293.73	.00	.83
Within-group	58	1006.41	17.35			
Total	59	6103.23				

Note. $^*p < .01$.

ANOVA results (see Table 1) revealed that there is a statistically significant difference in means for achievement test scores ($F(1, 59) = 293.73$, $p < .01$, $\eta^2 = .83$) between the revised chapter group ($M = 47.48$, $SD = 2.13$) and the unrevised chapter group ($M = 29.05$, $SD = 5.48$). The results indicated that participants' achievement test scores in the revised chapter group were better than in the unrevised chapter group, and the effect size was large.

4.2. Eye tracking results

A Mann-Whitney U non-parametric test was conducted to compare the means for the percentages of transitions in the unrevised and revised chapter groups, since the sample size is small for this eye tracking measure. The results showed that there was significant difference in means for integrative transitions ($U = 23.00$, $p < .05$), text-to diagram transitions ($U = 23.00$, $p < .05$), corresponding transitions ($U = .00$, $p < .05$) and proportion of corresponding transitions ($U = 23.00$, $p < .05$) between groups as summarized in Table 2. The result for the percentage of integrative transitions may imply that the participants in the revised chapter group ($M = 23.22$, $SD = 5.14$) attempted to integrate relevant words and relevant pictures significantly more than participants in the unrevised chapter group ($M = 15.55$, $SD = 4.34$). Similarly, the results for text-to-diagram transitions may imply that the participants in the revised chapter group ($M = 11.85$, $SD = 3.10$) attempted to integrate relevant words and relevant pictures significantly more than participants in the unrevised chapter group ($M = 7.74$, $SD = 2.16$).

Table 2. Mann-Whitney U test results table for the effects of multimedia learning design and visual design on transitions (in percentage)

Groups	*N*	Mean Rank	*U*	*Z*	*p*
Integrative transitions					
Unrevised chapter	15	9.53	23.00	-3.09	.00*
Revised chapter	11	18.91			
Text-to Diagram Transitions					
Unrevised chapter	15	9.53	23.00	-3.09	.00*
Revised chapter	11	18.91			
Corresponding transitions (total)					
Unrevised chapter	15	8.00	.00	-4.28	.00*
Revised chapter	11	21.00			
Proportion of corresponding transitions (Total)					
Unrevised chapter	15	8.00	.00	-4.28	.00*
Revised chapter	11	21.00			
Corresponding transitions (Text-to-diagram)					
Unrevised chapter	13	7.00	.00	-4.24	.00*
Revised chapter	12	19.50			
Proportion of corresponding transitions (Text-to-diagram)					
Unrevised chapter	13	7.08	1.00	-4.19	.00*
Revised chapter	12	19.42			

Note. $^*p < .05$.

Another similar result was that the percentage of total corresponding transitions had a significantly higher mean ($U = .00$, $p < .05$) for the revised chapter group ($M = 18.87$, $SD = 3.58$) than for the unrevised chapter group ($M = 8.65$, $SD = 2.57$). The percentage of text-to-diagram corresponding transitions had a significantly higher mean ($U =.00$, $p < .05$) for the revised chapter group ($M = 9.58$, $SD = 2.15$) than for the unrevised chapter group ($M = 3.29$, $SD = 1.00$). The mean for proportion of total corresponding transitions was also significantly higher ($U = 1.00$, $p < .05$) for the revised chapter group ($M = .82$, $SD = .08$) than for the unrevised chapter group ($M = .49$, $SD = .08$). These results implied that the revised textbook chapter group was significantly more successful at integrating words and pictures than was the unrevised chapter group.

A normality assumption for ANOVA was satisfied for the majority of eye tracking measures (*p* > .05) except visit duration on relevant images in the revised chapter group, but ANOVA was conducted since this statistic is robust to violations of the normality assumption (Field, 2016). The homogeneity of variance assumption was satisfied for the visit count on relevant texts (*p* > .05) and the visit count on relevant images (*p* > .05). However, the data for total fixation duration on relevant texts (*p* < .05), total fixation duration on relevant images (*p* < .05), visit duration on relevant images (*p* < .05) and visit duration on relevant texts (*p* < .05) violated the assumption. Similarly, the homogeneity of variance assumption was violated for the proportion of fixations on relevant texts (*p* < .05) and the proportion of fixations on relevant images (*p* < .05) (Field, 2016). Although the assumption was violated for these measures, the sample sizes for both groups were equal and *p* value was decreased from .05 to .01 to conduct one-way ANOVA for these measures, as well as conducting Welch and Brown-Forsythe corrections (*p* = .00) (Field, 2016).

Table 3. Descriptive statistics for eye tracking measures on relevant images

Eye tracking measures		Unrevised chapter		Revised chapter	
	n	*M*	*SD*	*M*	*SD*
Proportion of fixations	30	.19	.05	.33	.08
Total fixation duration	30	6.19	2.78	10.52	4.06
Visit duration	30	9.37	3.14	15.18	4.86
Visit count	30	14.06	4.88	19.76	5.68

ANOVA results for eye tracking measures (see Table 3 and Table 4) revealed that means for the proportion of fixations on relevant images in the control group (*M* = .19, *SD* = .05) and the experimental group (*M* = .33, *SD* = .08) differed significantly from each other, $F(1, 58) = .60.86$, $p < .01$, $\eta^2 = .51$. For total fixation duration on relevant images, the difference in means between the experimental group (*M* = 10.52, *SD* = 4.06) and the control group (*M* = 6.19, *SD* = 2.78) was statistically significant, $F(1, 58) = 23.27$, $p < .01$, $\eta^2 = .29$.

Table 4. One-Way ANOVA summary table for the effects of multimedia learning design and visual design on eye tracking measures on relevant images

Variable and source	*df*	*SS*	*MS*	*F*	*p*	η^2
Proportion of fixations						
Between-group	1	.30	.30	60.86	$.00^{*}$	.51
Within-group	58	.28	.00			
Total	59	.58				
Total fixation duration						
Between-group	1	281.72	281.72	23.27	$.00^{*}$	.29
Within-group	58	702.24	12.11			
Total	59	983.96				
Visit duration						
Between-group	1	505.67	505.67	30.21	$.00^{*}$	.34
Within-group	58	970.69	16.74			
Total	59	1476.37				
Visit count						
Between-group	1	487.24	487.24	17.39	$.00^{**}$	.23
Within-group	58	1625.21	28.02			
Total	59	2112.45				

Note. $^{*}p < .01$, $^{**}p < .05$, η^2 = effect size.

Similarly, ANOVA was significant for visit duration on relevant images, $F(1, 58) = 30.21$, $p < .01$, $\eta^2 = .34$. The results showed a statistically significant difference in means between the experimental group (*M* = 19.76, *SD* = 5.68) and the control group (*M* = 14.06, *SD* = 4.88) for visit count on relevant images, $F(1, 58) = 17.39$, $p < .05$, $\eta^2 = .23$. All the results showed large effect sizes for the eye tracking measures. The results indicated that the participants in the experimental group showed significantly more interest in relevant images in the revised chapter than the control group showed in relevant images in the unrevised chapter. The experimental group also focused on relevant images significantly more often than did the control group.

The results showed that the means differed significantly for the proportion of fixations on relevant texts as summarized in Table 6, $F(1, 58) = .60.86$, $p < .01$, $\eta^2 = .51$. The results implied that the participants in the control group (*M* = .81, *SD* = .05) paid significantly more attention to relevant texts than the experimental group (*M* = .67, *SD* = .08) (see Table 5).

Table 5. Descriptive statistics for eye tracking measures on relevant texts

Eye tracking measures		Unrevised chapter		Revised chapter	
	n	*M*	*SD*	*M*	*SD*
Proportion of fixations (%)	30	.81	.05	.67	.08
Total fixation duration (%)	30	27.07	10.56	21.71	7.27
Visit duration (%)	30	44.73	10.14	32.91	6.56
Visit count (%)	30	18.30	5.82	24.68	5.81

The ANOVA result was significant for total fixation duration on relevant texts, F (1, 58) = 5.26, p < .01, η^2 = .08 (see Table 6). The result implied that the participants in the unrevised chapter group (*M* = 27.07, *SD* = 10.56) paid significantly more attention to relevant texts than in the revised chapter group (*M* = 21.71, *SD* = 7.27; Johnson & Mayer, 2012).

Table 6. One-Way ANOVA summary table for the effects of multimedia learning design and visual design on eye tracking measures on relevant texts

Variable and source	*df*	*SS*	*MS*	*F*	*p*	η^2
Proportion of fixations						
Between-group	1	.30	.30	60.86	$.00^{*}$	.51
Within-group	58	.28	.00			
Total	59	.58				
Total fixation duration						
Between-group	1	432.16	432.16	5.26	$.03^{*}$	.08
Within-group	58	4769.08	82.23			
Total	59	5201.24				
Visit duration						
Between-group	1	2094.36	2094.36	28.73	$.00^{*}$	.50
Within-group	58	4228.39	72.90			
Total	59	6322.75				
Visit count						
Between-group	1	609.86	609.86	18.04	$.00^{**}$	.24
Within-group	58	1960.58	33.80			
Total	59	2570.44				

Note. $^{*}p$ < .01, $^{**}p$ < .05, η^2 = effect size.

For visit duration, the means also differed significantly between the unrevised chapter and the revised chapter groups, F(1, 58) = 28.73, p < .01, η^2 = .50 (see Table 6). The result for visit duration on relevant texts implied that the participants in the unrevised chapter group (*M* = 44.73, *SD* = 10.14) spent much more time on relevant texts to get general information in order to complete the achievement test than the revised chapter group (*M* = 32.91, *SD* = 6.56) (Holmqvist et. al, 2011). ANOVA results were also significant for visit count on relevant texts, F(1, 58) = 18.04, p < .05, η^2 = .24 (see Table 6). The percentage of visit counts on relevant text in the revised chapter group *(M* = 24.68, *SD* = 5.81) were significantly higher than the old chapter group's percentage (*M* = 18.30, *SD* = 5.82). This result indicated that both groups may have showed different interest in relevant texts during eye tracking sessions.

5. Discussion

Research results showed that participants using the revised textbook chapter performed better on the achievement test than participants using the unrevised textbook chapter during eye tracking sessions, and the effect size was large. This result was similar to several research results suggesting that using several principles for multimedia learning and visual design facilitated learning (e.g., Alpan, 2004; Boucheix & Lowe, 2010; Cheng et al., 2015; Eitel et al., 2013; Johnson & Mayer, 2012; Mayer et al., 1996; Molina et al., 2018; Ozcelik et al., 2009; Ozcelik et al., 2010; Peterson, 2016). For example, Alpan's (2004) research results suggested that students using a booklet with holistic visual design scored significantly better than the other group. Boucheix and Lowe (2010) reported that color cues helped participants get higher scores than arrow cues or no cues in their study. Similarly, another study revealed that signals fostered learning and participants who studied with signaled material performed better than participants who studied the material with no signals (Ozcelik et al., 2010). Another research result showed that participants' retention and transfer performance increased when color codes were used (Ozcelik et al., 2009). For the spatial contiguity principle, Johnson and Mayer's (2012) research results revealed that text and image integration helped participants in experiment groups to outperform other groups on transfer tests.

For the multimedia principle, one study showed that the group who received the summary with text and visuals performed as well as or better on recall questions and transfer problems than students in other groups (Mayer et al., 1996). In another study, learning outcomes were better based on recall and comprehension scores when visuals were presented in a self-paced format, both before and concurrently with the text rather than presenting only the text (Eitel et al., 2013). Molina et al. (2018) showed that presenting image and text together resulted in significantly higher post-test scores than presenting text only. Another study revealed that a modified textbook which aligned with several principles of multimedia learning (the multimedia principle, modality, the split attention effect, and the avoiding redundancy effect) helped students to perform better on conceptual knowledge, transfer and retention tests than students in a group using the standard textbook (Cheng et al., 2015). However, current research results regarding achievement test scores were different from some other research results in the literature because the post-test scores did not differ significantly between groups when using several multimedia principles (signaling, contiguity, and coherence) together, or using spot-light cues, or using proximity in multimedia learning materials in those studies (Clinton et al., 2016; de Koning et al., 2010; Molina et al., 2018).

Eye tracking results supported the impact of multimedia learning design and visual design on achievement test scores, as the participants in the revised chapter group attempted to integrate relevant text and relevant pictures significantly more often and were significantly more successful than participants in the unrevised chapter group. The research results were similar to Johnson and Mayer's (2012) research results. The participants in the revised chapter group paid significantly more attention to relevant images than the participants in the unrevised chapter group based on proportion of fixations, total fixation duration and visit duration. These results were similar to various studies in the literature (e.g., Boucheix & Lowe, 2010; de Koning et al., 2010; Eitel et al., 2013; Molina et al., 2018; Ozcelik et al., 2009; Ozcelik et al., 2010). There was a large effect size for each of the eye tracking metrics in this study.

Research results regarding proportion of fixations, total fixation duration and visit duration were different from some other research results in the literature (Clinton et al., 2016; Johnson & Mayer, 2012). Clinton et al. (2016) showed that participants with low prior knowledge had higher total fixation duration on relevant images in the control group than the experimental group. However, the participants in the revised chapter group paid significantly more attention to relevant images than the participants in the unrevised chapter group based on proportion of fixations, total fixation duration and visit duration in this study. Another study revealed that the proportion of fixations, total fixation duration and visit duration did not differ significantly between two groups in three different experiments using the spatial contiguity principle (Johnson & Mayer, 2012). The difference in current research results may arise from investigating several principles of multimedia learning and visual design holistically in this study. The student participants of the study were also between Piaget's concrete operational stage and formal operational stage, and this characteristic may be considered as a confounding variable in future studies (Piaget, 1997).

Research results also showed that participants in the revised chapter group were significantly more interested in relevant images than participants in the unrevised chapter group, based on visit count similar to other measures for cognitive processing (Holmqvist et al., 2011). This result aligned with the results related to transitions measured in this study. From an ease-of-use perspective taken from usability studies, higher visit counts show the difficulty of an instrument (Holmqvist et al., 2011), but this eye tracking measure on relevant images in textbooks and similar educational materials can be explored in future studies for similarity or differences in research results.

Eye tracking results for relevant text were different as participants in the unrevised chapter group paid significantly more attention to relevant text than did participants in the revised chapter group based on proportion of fixations, total fixation duration, and visit duration measures. The research result was similar to other research results indicating that using several multimedia design principles decreases the time spent on relevant texts for experimental groups (Eitel et al., 2013; Molina et al., 2018). Nevertheless, research result was different from some other research results in the literature (Clinton et al., 2016; Johnson & Mayer, 2012; Ozcelik et al., 2009). However, Ozcelik's et al. (2009) research results suggested that higher fixation duration on relevant texts results in worse performance. Thus, current research results may also suggest that participants may have spent more time on relevant texts when they didn't find the answer for the questions related to relevant images through their cognitive processes. Differently for relevant texts, the results indicated that the revised chapter group showed more interest in relevant texts than the unrevised chapter group based on visit count measure. Relevant texts in the revised chapter may provide more semantic informativeness than relevant texts in the unrevised chapter

(Holmqvist et al., 2011). The effect sizes were large. This result also aligned with the results related to transitions measured in this study.

This study also differed from other studies in the literature by testing participants' science achievement during the studying process from a usability testing perspective rather than using the post-test at the end of the studying/eye tracking sessions (e.g., Alpan, 2004; Boucheix & Lowe, 2010; Cheng et al., 2015; Clinton et al., 2016; de Koning et al., 2010; Eitel et al., 2013; Johnson & Mayer, 2012; Mayer et al., 1996; Mayer et al., 1995; Molina et al., 2018; Ozcelik et al., 2009; Ozcelik et al., 2010; Peterson, 2016).

In this study, the student participants' science achievement and cumulative school achievement were higher than the other students in the school. It was assumed that their reading comprehension was also better than the others, as there is a correlation between reading comprehension and science achievement in the literature (Cromley et al., 2010). However, one study revealed a negative correlation between reading comprehension ability and the first-pass fixation time on the text (Mason et al., 2013). For this reason, the reading comprehension characteristics of participants can be taken into account in future studies. This study was also conducted using a printed multimedia learning material, while other studies used digital versions of the multimedia learning materials, and student-reading behavior may differ when studying with printed learning material as compared to studying with digital learning material (Wallis, 2017).

In this study, all the results for eye tracking measures have both similarities and differences with other research results in the literature (e.g., Boucheix & Lowe, 2010; Clinton et al., 2016; de Koning et al., 2010; Eitel et al., 2013; Johnson & Mayer, 2012; Molina et al., 2018; Ozcelik et al., 2009; Ozcelik et al., 2010). The other studies examined only one principle or a few principles of multimedia learning design, but this study examined several multimedia learning design principles and visual design principles at once, and consequently, this approach may have provided different results from the literature. Therefore, examining multimedia learning design and visual design in a holistic approach can contribute to the literature by testing the design principles of science textbooks in real world settings, as investigating different multimedia learning design principles at once in diverse materials was suggested in the literature (Clinton et al., 2016; Jarodzka et al., 2017). The results can also contribute to the literature by examining multimedia learning design and visual design of science textbooks with young learners as the target learner group (Jarodzka et al., 2017; Mason et al., 2013; Molina et al., 2018).

6. Conclusions

This study investigated students' studying process using a 6th grade public school science textbook as a multimedia learning material. Research results revealed that multimedia learning and visual design of the revised cell biology chapter facilitated students' studying processes and helped attentional focus on relevant images and integration of relevant texts and relevant images during their learning processes when the cell biology chapter of a 6th grade science textbook was redesigned based on certain principles of CTML and visual design. Two categories were established: visual design and multimedia learning design.

The research results also supported using multimedia learning design and visual design holistically in science textbook design. Applying design principles holistically in the revised cell biology chapter resulted in significantly less time spent on relevant texts, significantly more successful integration of relevant texts and relevant images as well as significantly higher achievement scores in the revised chapter group as compared to unrevised old chapter group. Thus, design principles can be used in a holistic way in science textbook design, and certain visual design principles can assist designers in a detailed way when applying multimedia learning design principles to science textbooks. These research findings can be used by experts in the design process to develop a science textbook based on learner needs as well as by teachers to select appropriate science textbooks for students. The research also provides theoretical implications for investigating CTML for younger learners in further research.

6.1. Implications for practice

The results also provide exemplary principles for designing similar multimedia learning materials using a holistic approach. These principles can also be used as criteria for evaluating science textbooks. Principles of multimedia, coherence, segmenting, signaling, personalization, pre-training, spatial contiguity, and split attention were among the selected CTML principles that can be used in science textbook design.

The principles of visual design resulting from this study consisted of 20 principles addressing visuals and overall layout (e.g., clarity, aesthetic proportion-balance, alignment, consistency, and unity) in science textbooks. The visual design principles used in the revision process included clarity, image, alignment, consistency, quality of paper-printing, simplicity, using blank space effectively, color selection, unity, accurate design, aesthetic proportion-balance, and design variations. Learner level, motivational elements using emotional design, individual differences, and establishing connection with daily life by using the cell factory analogy were also addressed during the revision process. Emotional design was applied to the revised chapter by using bright or vivid colors, especially red to guide learners' attention in overall design including titles and cues. Other colors in illustrations or images were selected among bright colors for the same purpose. Another revision related to emotional design included using comic characters for cell biology analogies to appeal to students as suggested in the literature (Mayer & Estrella, 2014; Stark et al., 2018).

6.2. Implications for future research

This study investigated student studying process using a science textbook that is used in Turkish public schools as a multimedia learning material. Future research may investigate the student learning process while using textbooks as multimedia learning materials in other fields such as math, language, social studies etc. as well as investigating learning process with a science textbook in other grade levels, and in different countries. Future studies can examine the difference between groups with first pass and second pass reading and inspection, and pattern analysis in eye-tracking results (Mason et al., 2013) can be applied. Cognitive load was not examined in this study, but future studies can explore whether there is a significant difference between the unrevised chapter group and the revised chapter group based on cognitive load for both relevant images and relevant texts. The research procedures can be replicated to investigate the multimedia learning design and visual design of digital materials for science education in future studies. The implications of the study may also be tested for digital science textbook design by using similar research procedures.

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