2018 ASEE Annual Conference & Exposition
June 24–27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #22805

Evaluating the Effects of Highlighting Text Animations on the Attention Distribution of Students with Math Learning Difficulties

Ms. Shuang Wei, Purdue University, West Lafayette

Shuang Wei is a Ph.D. student in the department of Computer Graphics Technology, Purdue University. She received her Master of Science degree from the same major and a Bachelor degree in digital media from Harbin Institute of Technology (China). Her research focuses on information visualization, human-computer interaction, and multimedia education.

Ms. Qingli Lei, Purdue University, West Lafayette
Dr. Yingjie Chen, Purdue University, West Lafayette

Dr. Yingjie Chen is an assistant professor in the Department of Computer Graphics Technology of Purdue University. He received his Ph.D. degree in the areas of human-computer interaction, information visualization, and visual analytics from the School of Interaction Arts and Technology at Simon Fraser University (SFU) in Canada. He earned the Bachelor degree of Engineering from the Tsinghua University in China, and a Master of Science degree in Information Technology from SFU. His research covers interdisciplinary domains of information visualization, visual analytics, digital media, and human computer interaction. He seeks to design, model, and construct new forms of interaction in visualization and system design, by which the system can minimize its influence on design and analysis, and become a true free extension of human's brain and hand.

Prof. Yan Ping Xin, Purdue University, West Lafayette

Dr. Yan Ping Xin is a Professor in the Department of Educational Studies at Purdue University. Her research interests include effective instructional strategies in mathematics problem solving, algebra readiness, and computer-assisted mathematics intervention programs for students with learning difficulties. Her recent research agenda focuses on developing Conceptual Model-based / Mathematics Intelligent Tutors and promoting the use of this evidenced–based intervention program by elementary school teachers/practitioners who work with at-risk students. Dr. Xin's work has been referenced in sources such as the National Mathematics Panel Final Report, the What Works Clearinghouse, and the Institute of Education Sciences Practitioner's Guide. Her Conceptual Model-based Problem-Solving approach is included in National Council of Teachers of Mathematics authorized book "Useful and Useable Research Related to Core Mathematical Practices" (Silver & Kenney, 2015, 235-246) to inform teaching practices in K-12 mathematics classrooms. Recently, she guest edited the Cross-disciplinary Thematic Special Series: Special Education and Mathematics Education in the journal Learning Disability Quarterly.

Dr. Signe Kastberg, Purdue University, West Lafayette
Soojung Kim , Purdue University, West Lafayette

Evaluating the effects of highlighting text animations on the attention distribution of students with math learning difficulties

Abstract:

Computer-assisted learning benefits students by providing a great number of multimedia resources for improving response strength, streamlining information acquisition, and promoting knowledge construction [1]. Highlighting techniques have been widely used and, within the framework of cognitive load theory, are recognized as effective methods guiding students' attention and reducing extraneous cognitive processes. This research study was designed to examine the effects of highlighting text animations (including blinking animation, popping out animation, and intense animation) on the attention distribution of students with math learning difficulties (MLD). As predicted, the results suggest that highlighting text animations are able to guide the attention allocation of students with MLD. In particular, intense animation significantly improved students' fixation duration ratios on the key information areas in comparison to situations without highlighting text animation.

1. Introduction

In 1959, researchers started to explore the possibilities of using computers as active elements in the instructional process. Since then, computer-assisted instruction (CAI) has been considered an effective method for improving students' learning skills and has been widely used in schools. To gain students' attention and increase their engagement, highlighting text animations such as popping-out, blinking, and coloring are used in many programs. Highlighting text animations can rapidly attract more attention to key information on the screen, helping students to efficiently transfer information. As one typical animation used in CAI, highlighting text animation has been proven to be an effective method for presenting information [2].

However, these studies' participants often are typically-developing students or adults. And in these studies, researchers use problem-solving correctness to indicate the effects of animation. In this paper, by contrast, researchers propose to use eye tracker to directly identify the effects of animation on students' attention distribution, since eye-tracking technology can accurately track students' gaze trajectory and gaze fixations.

We recruited both typically developing students and students with math learning difficulties (MLD) to answer three research questions:

Do highlighting text animations effect the attention distribution of students with MLD?

How were students with MLD influenced by highlighting text animations?

Did highlighting text animations have different effects on students with MLD and on typically developing students?

2. Literature Review

Historically, learning disability (LD) was based on IQ-achievement discrepancy. However, such a discrepancy model does not help us to define MLD [3, p. 143]. The DSM-IV-TR also agrees: "Particularly when Mathematics Disorder is associated with High IQ, the child may be able to function at or near grade level in the early grades, and Mathematics Disorder may not be apparent until the fifth grade or later" [11, p. 108]. MLD, which is also referred to as dyscalculia, is a specific type of learning disability related to neurologically-based disorders in mathematics ability [5, p. 2]. Similar to Reading Disability (RD), there is a significant portion (roughly 6%) of the population that has MLD [3 , p. 143]. Although performance in math has a significant influence on one's success in adulthood, MLD has traditionally received much less attention from researchers in comparison to RD. Therefore, the study of MLD is becoming an increasingly attractive research area [3 , p. 143].

Gagne [5] proposed that using animation is an important way to provide instruction because it helps capture students' attention. Moreover, animation can be used to provide feedback to students in structured practice activities in question and answer contexts [2]. In addition, R. E. Mayer and Anderson [6] did a computer-based instruction to examine some of the conditions that can affect animations, concluding that integrating words and animations (pictures) during instruction is an effective learning strategy.

Yeari, Oudega, and van den Broek [7] studied eye movements to investigate whether highlighting can affect online processing and offline memory for illustrative texts. Their results demonstrated that, although highlighting does not affect processing when readers first come across a text, it does increase the time readers spend concentrating on the text. Moreover, Burling and Yoshida [8] developed two experimental studies about the importance of using highlighting to shift early children's attention. In sum, these two experimental studies provide evidence that highlighting affects children's attention between the ages of 3 to 6.

This study was conducted in order to examine the effects that highlighting animations can have on the attention distribution among a group of 2nd or 3rd grade elementary school students with MLD. Typically developing students in 2nd or 3rd grade who were also recruited in this study constituted the control group to serve as the baseline. The authors of this study investigate four general hypotheses:

1. When reading question content without highlighting text animation, typically developing students demonstrate a significantly higher AOI fixation ratio (the total duration of fixation located within AOI to the total duration of fixation located within the screen) than students with MLD.
2. When reading question content with highlighting text animation, the AOI fixation ratio difference between students with MLD and typically developing students will decrease.
3. Highlighting text animation significantly improves the AOI fixation ratio of students with MLD.

4. Highlighting text animation leads to an overall shift of the attention distribution of students with MLD.

3. Methodology

3.1 Participants

Ten 2nd and 3rd grade students with MLD from an elementary school located in the Midwestern United States took part in the study. Initially, teachers recommended individual students for the experiment; then, the students took the SAT Math test. All participating students' SAT scores were below the 30% percentile, which qualified them as having MLD. In addition, five typically developing students were recruited to form the control group for the study.

However, once disqualifying features (such as no eye tracking data captured or a relatively low percentage of eye tracking data collected) were taken into account, the number of qualifying participants was down to six students with MLD and four typically developing students. The age distribution of participants was balanced as much as possible: five (50%) second-grade students and five (50%) third-grade students, six (60%) of whom were female and four of whom (40%) were male.

3.2 Rooms and Equipment

The study was conducted in two separate sessions. As a part of a National Science Foundation (NSF) funded project [10], students with MLD took the test in the school's computer lab. Typically developing students worked with the computer program in a public library.

Students worked one-on-one with the computer program on laptops with 25-inch displays. A Tobii Pro X3-120 eye tracker (120HZ) was installed on the laptops to record students' gaze movement and interactive behavior. Their eye movement data were automatically stored in Tobii Studio 3.4.5 for future analysis.

3.3 Design

This study was designed to include an experimental group and a control group, as well as three conditions (intense animation, popping-out animation, and blinking animation). For each condition, there was a preparation episode in which students read the question content without animation (Table 1). A within-subject design was applied to increase the statistical power of the study. Each participant took part in all three conditions.

3.4 Study material and procedure

To create the procedure, three questions were taken from a Conceptual Model-based Program Solving (COMPS) tutor, developed to promote the additive mathematics problem-solving of students with MLD. The tasks emphasized understanding mathematical relations in real-world problems to benefit students' ability to create algebraic equations. Figure 1 presents one of the tasks that students attempted in the study. An audio recording was played with the task to instruct students about how to solve the problem. First, the whole question was read to the students without highlighting text animation. Then, a detailed instruction was provided with highlighting text animation. Here is one such instruction: “This problem has three parts: the total number of songs Gilbert wrote, the number of songs Bob wrote, and the number of songs they wrote in all.” After these instructions, students were required to label each of the three boxes in the diagram equation (Figure 1) using the name tags provided in the problem. The three questions applied the same Part-Part-Whole math concept with different scenarios, numbers, and highlighting text animations. In the three questions, the highlighting text animations employed were popping-out name tags, blinking sentences, and intense animation. Intense animation includes popping-out name tags, blinking sentences, and coloring sentences, which are played successively.

After the participants were seated in front of computer screens, researchers told them which tasks they were going to do, calibrated the eye-tracking system, and started recording. Then students took control of the computers and started their tasks. Unlike many studies conducted in highly-controlled experiment environments, researchers left the area after setting up the program to create a more naturalistic situation for students. Also, since Tobii Pro X3-120 is ultra slim (324*20*17mm) and mounted at the bottom of the laptop screen, students were not distracted by the eye tracker during their learning.

In a more naturalistic situation, students will not feel be monitored and will behave naturally. Then, students’ eye movements data could help researchers understand students’ attention distribution in the real world. However, the naturalistic situation also added challenges for eye movement data collection and data analysis, since students sometimes would lose attention, move around in their seat, or lie down on the table, making it difficult to capture eye movement.

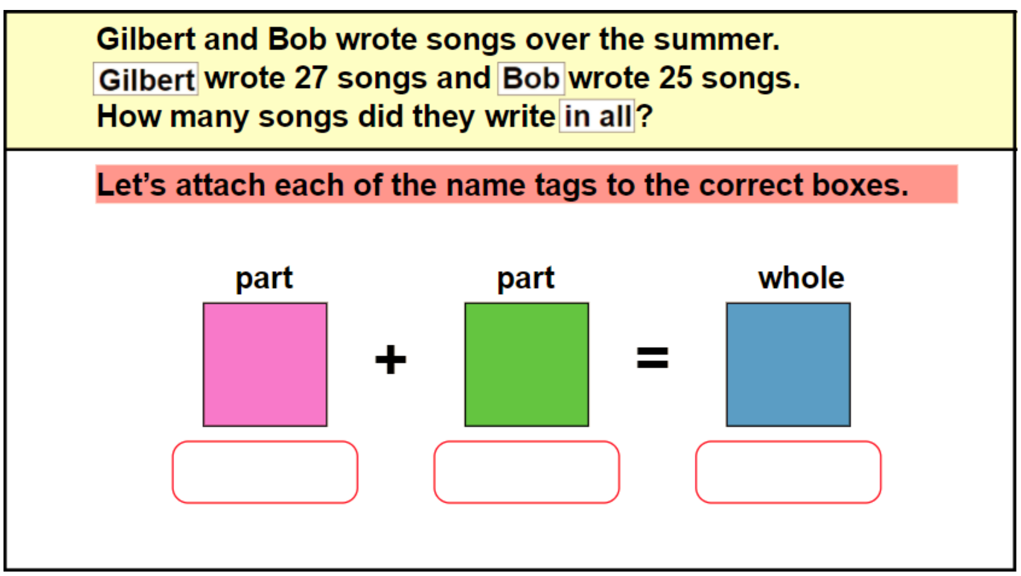


Figure 1: An illustration of COMPS tasks [10]

4. Data Analysis

Tobii Studio was used to organize and export eye movement data, while Microsoft Excel and RStudio were used to analyze this data. In Tobii Studio, researchers identified the starting and ending points of segments with or without highlighting text animations. Within the segments, question content area (yellow area in Figure 1) was defined as the area of interest (AOI). Then, segment duration (in milliseconds), eye movement type (fixation, saccade, or unclassified), fixation duration (in milliseconds), fixation position in X direction (in pixels), fixation position in Y direction (in pixels), and AOI (1=the fixation is located inside of the AOI, 0=the fixation is not located inside of the AOI) were exported as Excel files. Eye movement videos also were exported so researchers could visually analyze students' change in attention over time.

There are two segments of each task/condition. The first segment involves reading the whole question content without highlighting text animation and the second segment involves giving detailed instructions with highlighting text animation. Since segments' durations vary, researchers used fixation ratios instead of absolute fixation durations to conduct statistical analysis.

First, since students' off-task behaviors led to many extreme AOI fixation ratios, the fixation ratio—the ratio of total fixation duration to segment duration—was checked to ensure that they paid attention to the tasks. For instance, when students were off task, they might randomly look at the screen for few seconds and experience fixation at a random location on the screen (AOI or white space). In this situation, since the short, random fixation was one of the only few fixations recorded, the AOI fixation ratio turned out to be either extremely low or extremely high, depending on the fixation's location. If included, these extreme values would result in serious bias, especially for a test with a small sample size. Therefore, researchers re-examined the videos of students who had extreme values and excluded the students who consistently showed off-task behaviors and had relatively low fixation durations. In the end, two students with MLD were excluded from participating in the experimental groups because the fixation ratios were under twenty percent. Besides that, another two students with MLD and one typically developing student were excluded because no eye tracking data was captured, since their position moved after eye tracking calibration.

Second, to provide an overview, the mean of AOI fixation ratio for each group under different tasks/conditions was calculated separately (Table 1). Then, the Wilcoxon Signed-rank test and the Mann-Whitney's U test were applied to determine whether significant differences existed between groups or conditions. These two tests are non-parametric versions of the paired t-test and one sample t-test, which are used when an experiment sample size is small, as it is in this test. The Wilcoxon Signed-rank test was used to analyze the differences between different conditions within the same group, while the Mann-Whitney's U test was used to analyze the differences between groups under the same conditions.

Condition1	N/A	Intense	Condition2	N/A	Popping-out	Condition3	N/A	Blinking
Experimental Group Mean	0.340	0.653	Experimental Group Mean	0.386	0.431	Experimental Group Mean	0.322	0.321
Control Group Mean	0.559	0.659	Control Group Mean	0.621	0.606	Control Group Mean	0.772	0.614
Mean Difference	-0.22	-0.006	Mean Difference	-0.24	-0.175	Mean Difference	-0.45	-0.29
P-value	0.057	0.543	P-value	0.033	0.129	P-value	0.009	0.057
Effect Size	0.539	0	Effect Size	0.607	0.405	Effect Size	0.742	0.539

Table 1. The statistics of experimental group and control group

5. Results

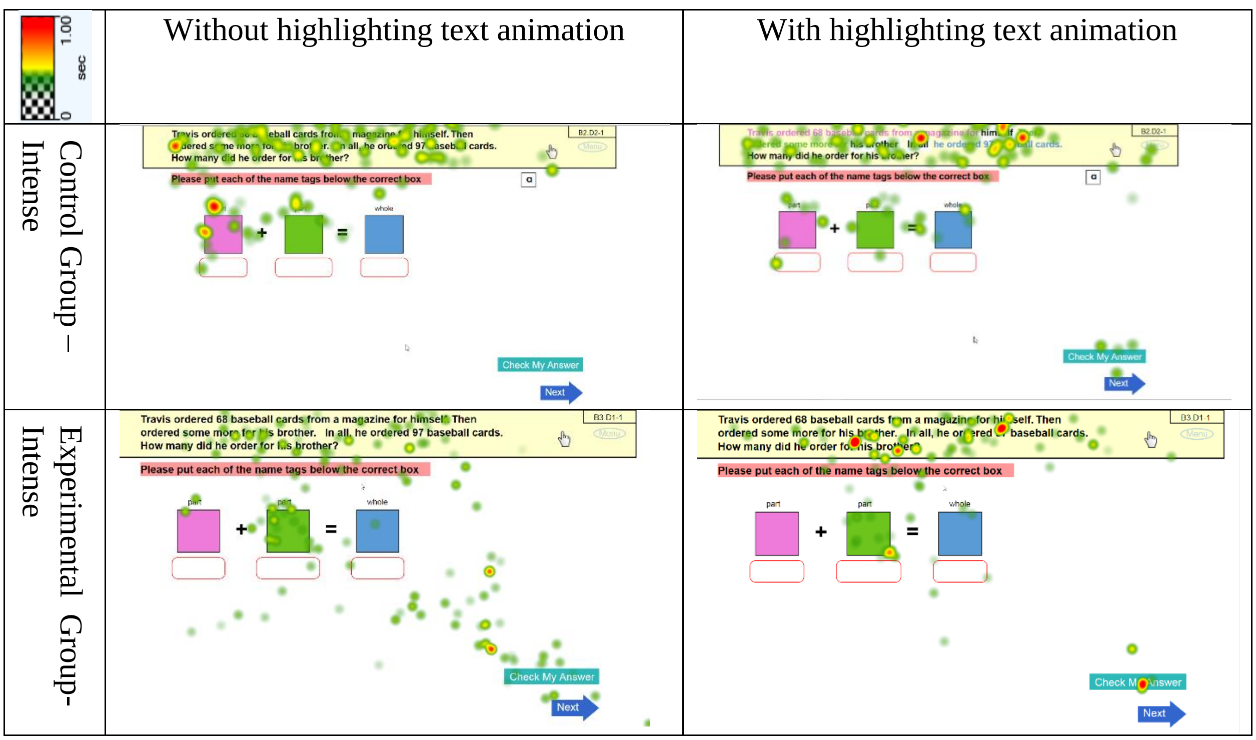
As Table 1 shows, AOI fixation ratio differences existed between the experimental group and the control group when there were no highlighting text animations. Typically developing students dwelled on the question content area with key information for a relatively long time (around sixty percent of the total fixation time), while students with MLD only spent about thirty-five percent of their fixations on the question content area. After adding intense animation, the AOI fixation ratio of students with MLD greatly increased to a level comparable with the AOI fixation ratio of typically developing students. But popping-out animation and blinking animation did not significantly increase the AOI fixation ratio for either the experimental group or the control group.

To prove *hypothesis 1*—that typically developing students have significantly higher AOI fixation ratios than students with MLD when there are no highlighting text animations—Mann-Whitney's U test was applied to calculate the one-sided p-value. A significance level of 0.05 was chosen. The results of Mann-Whitney's U test are listed in Table 1. The table shows that in conditions 2 and 3, the p-value is smaller than 0.05. Then, researchers averaged the AOI fixation ratios among different conditions, as there was no highlighting text animation in any of the three conditions. The mean AOI fixation ratio difference between the experimental group and the control group is 0.301, the p-value is 0.005, and the effect size is 0.809. This result proves hypothesis 1, that typically developing students spent significantly higher ratios of fixation time on the question content area when compared with students with MLD.

To test *hypothesis 2*—that the highlighting text animations decrease the AOI fixation ratio difference between typically developing students and students with MLD—the AOI fixation ratio differences between the two groups of students were calculated and listed in Table 1. Comparing the AOI fixation ratio differences between the two groups before and after adding highlighting text animations (Table 1) revealed that the differences are indeed decreased to varying degrees. So hypothesis 2 was proven to be true.

Hypothesis 3 proposed that the highlighting text animations significantly increase the AOI fixation ratio of students with MLD. The mean AOI fixation ratios of students with MLD in Table 1 do present ratio increase. For popping-out animation, there was some increase in the AOI fixation ratio, compared with the no-animation segment, but the increase was small (Increase=0.045, p=0.421, Effect size=0.09). For blinking animation, the AOI fixation ratio change was fairly minor (Increase=-0.001, p=0.421, Effect size=0.09). Only intense animation led to a significant increase in the AOI fixation ratio of students with MLD (Increase=0.313). The Wilcoxon Signed-rank test was used to check the significance. The result showed that intense animation significantly increased the AOI fixation ratio of students with MLD (p=0.0469, Effect size=0.514). Thus, hypothesis 3 was partially proved.

Researchers used heatmaps (Figure 2) to prove *hypothesis 4*, that the highlighting text animations cause the attention distribution shifts of students with MLD. In Figure 2, the first row shows the typically developing students' attention distribution through heatmaps. Their attention distributions revealed no real change. Both the segment without a highlighting text animation and the segment with a highlighting text animation shared the same patterns: focusing on the key information area (question content area), glancing at relevant elements (boxes and buttons), and ignoring irrelevant area (white area). For students with MLD, however, when there was no highlighting text animation, their attention distribution was widely spread across the screen (heatmaps in the second column and three to five rows). They dwelled on key information areas, gazed at relevant elements, and also glance around white space.



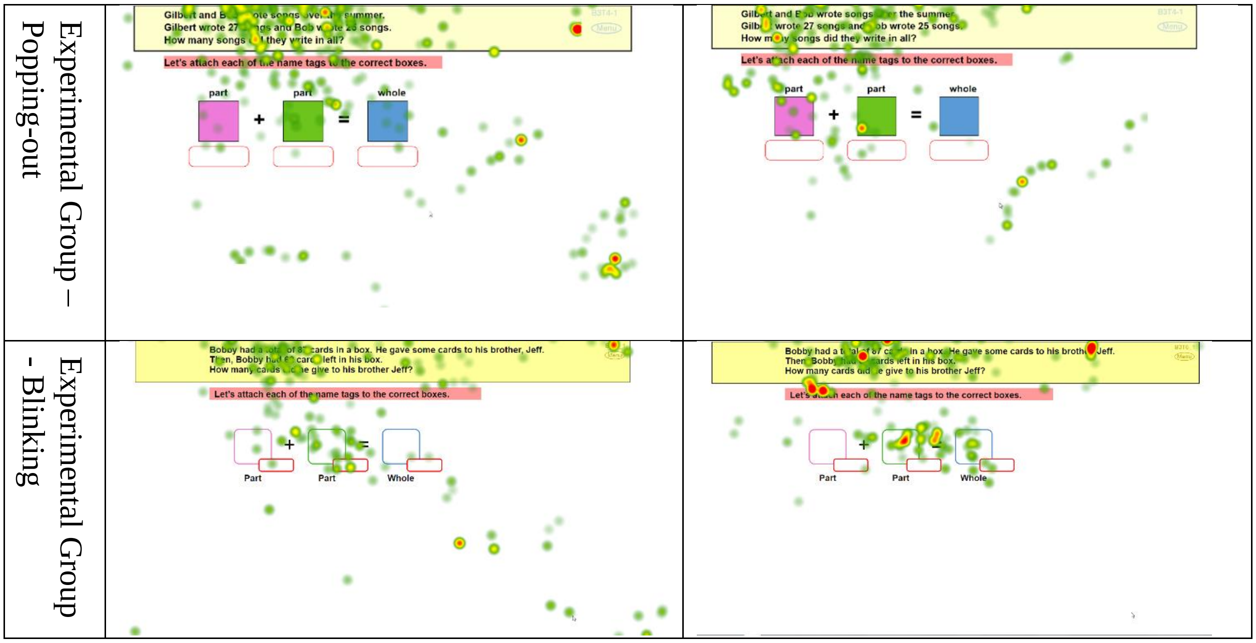


Figure 2. Fixation heatmaps of students

From the heatmaps in the third column, it can be observed that the attention patterns of students with MLD were altered by the highlighting text animations. They shifted more of their attention to the question content areas and relevant element areas. Also, fixations on white space decreased greatly. Researchers were curious about what caused the fixation aggregation in the white space in popping-out animation heatmaps of the experimental group (third column and fourth row). Researchers examined videos and found that one student right clicked the mouse, opening the right-click menu. As she was not totally off-task but playing while learning, her fixation ratio was above the exclusion criteria (the AOI fixation ratio <0.2), so her eye movement data were kept. Thus, hypothesis 4 has been proven. Even when the AOI fixation ratio's increase is insignificant, with the effect of highlighting text animations, the attention distribution of students with MLD shifted in the direction of key information areas and relevant element areas.

6. Discussion and Conclusions

The results presented suggest that highlighting text animations have important effects on the attention distribution of students with MLD. Intense animation consisting of popping-out animation, blinking animation, and coloring animation significantly increased the AOI fixation ratio and attracted more attention to question content areas for students with MLD. Besides that, blinking and popping-out animations greatly decreased students' attention to white space. Most importantly, highlighting animations helped students with MLD devote more attention to the important information in the questions. Without highlighting text animations, the duration of individual fixation located within the question content area was consistently less than one second. And students distributed their attention evenly on the question content area. Because of this, there were barely any red dots in the experimental group's heat maps (without highlighting text animation). With highlighting text animation, some fixations' durations increased to more than one second. Since longer fixation duration indicates longer processing-time [9], highlighting text animations led students with MLD to better emphasize, process, and understand key bits of information.

In contrast to students with MLD, the eye tracking data analysis results indicated that highlighting text animations have no significant effect on typically developing students. However, this result may have been influenced by the study environment of their session. Instead of taking the test in their school's computer lab like the experimental group, the typically developing students took the test in a public library. Although researchers tried to create a naturalistic environment for them, the quiet yet unfamiliar space of the library may have reminded them of the experimental purpose of the test. Therefore, they were engaged, producing relatively high AOI fixation ratios, at least at the beginning of the test. Typically developing students illustrated what attention distribution should look like in the state of concentration.

In this study, we investigated the effects of different highlighting text animations on students with MLD as well as the differences between students with MLD and normally developing students. The results show that intense animation has a significant effect on the attention distribution of students with MLD and is able to increase the AOI fixation ratio of typically developing students. Highlighting text animation can illustrate key information for students with MLD and guide them to spend more time on learning key information.

This study highlights the important role played by highlighting text animation in guiding the attention distribution of students with MLD and proves the effectiveness of intense animation. For students with MLD, a stronger stimulus is needed to attract and hold attention. Because MLD students are sensitive to stimulus, irrelevant operations (such as right-click) and non-essential information (such as toolbar and bookmarks bar) in web-based computer-assisted learning programs should be avoided.

In future studies, more types of highlighting text animations should be analyzed, and the effects of different degrees of intensity in highlighting text animation should be studied in detail. Also, more participants should be recruited to increase the reliability of the results.

References

[1] R. E. Mayer, *The Cambridge handbook of multimedia learning*. Cambridge: Cambridge University Press, 2014.

[2] L. P. Rieber, “Animation in computer-based instruction,” *Educ. Technol. Res. Dev.*, vol. 38, no. 1, pp. 77–86, Mar. 1990.

[3] E. Wadlington and P. L. Wadlington, “Helping students with mathematical disabilities to succeed,” *Prev. Sch. Fail. Altern. Educ. Child. Youth*, vol. 53, no. 1, pp. 2–7, Sep. 2008.

[4] M. M. M. Mazzocco and R. E. Thompson, “Kindergarten predictors of math learning disability,” *Learn. Disabil. Res. Pract.*, vol. 20, no. 3, pp. 142–155, Aug. 2005.

[5] R. Gagne, *The Conditions of Learning*. 1965.

[6] R. E. Mayer and R. B. Anderson, “The instructive animation: Helping students build connections between words and pictures in multimedia learning,” *J. Educ. Psychol.*, vol. 84, no. 4, pp. 444–452, 1992.

[7] M. Yeari, M. Oudega, and P. van den Broek, “The effect of highlighting on processing and memory of central and peripheral text information: evidence from eye movements,” *J. Res. Read.*, vol. 40, no. 4, pp. 365–383, Nov. 2017.

[8] J. M. Burling and H. Yoshida, “Highlighting in early childhood: Learning biases through attentional shifting.,” *Cogn. Sci.*, vol. 41 Suppl 1, no. Suppl 1, pp. 96–119, Feb. 2017.

[9] A. Poole and L. J. Ball, “Eye tracking in human-computer interaction and usability research: Current Status and Future Prospects,” *Encycl. Human-Computer Interact.*, pp. 211–219, 2005.

[10] Y. P. Xin, S., Kastberg, and Y. J., Chen, *Conceptual Model-based Problem Solving (COMPS): A Response-to-Intervention Program for Students with Learning Difficulties in Mathematics.*National Science Foundation funded project.2015.

[11] S. S. Zentall, Students with Mild Exceptionalities (Characteristtics and Applications). 2014.