Exploring the Utility of Eye-tracking in Identifying Misconceptions in a Digital Mathematics Game

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Abstract: This qualitative study investigates how students' eye movement patterns may be indicative of their mathematics misconceptions in a digital learning environment, ST Math. Third-graders solved mathematics problems from two content areas. Although in the content area "area/perimeter," eye-tracking data only reflected some categories of misconceptions, the correspondence between students' misconception groups and gazing patterns in the content area "fractions on a number line" showed the potential of eye-tracking as a way to diagnose mathematics misconceptions.

Introduction

Conceptual change requires learners to adjust existing mental schemas to accommodate new ideas (Sanger & Greenbowe, 2000), and one of the first steps in conceptual change is to identify a misconception (Uzuntiryaki & Geban, 2005). Many personalized digital learning environments have been designed and developed, focusing on learner ability, diagnosing groups, or scoring mechanisms (e.g., Lau & Yuen, 2010); however, few studies have investigated the kinds of misconceptions exhibited in digital environments nor interventions to address them (Chen, 2011). Eye-tracking technology offers information of visual attention, providing insight of ongoing cognitive processes (Bolden et al., 2015). Previous eye-tracking studies in digital learning environments have focused on the relationship between gaze patterns and comprehension process (Shayan et al., 2017) or problem-solving strategies (e.g., Tsai et al., 2019). We posit that it is possible that eye-tracking data could also help identify indicators of misconceptions. Using eye-tracking data, this poster investigates how students' eye movement patterns may be indicative of their mathematics misconceptions in a digital learning environment.

Methodology

This study was situated within a larger research project that investigated mathematics learning and assessment in a computer-based learning environment. Participants included 34 third-grade students across a set of schools in the same Midwestern school district. Students solved digital mathematics problems from two content areas – fractions on a number line and area/perimeter, which were selected from ST Math, a game-based instructional software developed by MIND Research Institute that presents mathematical concepts visually and connects the ideas to symbols and language. The data sources (from 28 participants with valid eye-tracking data) included cognitive lab video recordings and eye-tracking data, which were analyzed separately. Students' think-aloud transcripts of incorrect responses were coded using predetermined coding schemes based on existing literature (Carle, 1993; Cavanagh, 2007; KY DOE, 2019; Machaba, 2016). For each problem, students were organized into different groups based on different identified misconceptions. For the eye-tracking data, heat maps (indicator of fixation) and gaze plots (sequence of fixations) were generated for each students' incorrect response. Descriptive coding was conducted on each plot with detailed features qualitatively evaluated to identify patterns across students. The coding groups from cognitive lab videos and from the eye-tracking were then compared to see which eye-tracking groups matched with misconception groups.

Results

Analyses showed correspondence of eye-tracking patterns to "fractions on a number line" misconceptions. For instance, in locating 1/8 on the number line, students showed one major category of misconception – using the whole number rule to count fractions on the number line, where students ordered fractions using the denominator. The separate analysis of eye-tracking data revealed that all students with this misconception showed the same visual pattern (e.g., Figure 1a). To locate 1/8 on the number line, students who incorrectly applied the counting rule of whole numbers (i.e., counting from the middle point of the number line 1/2 to the right as 1/3, 1/4 until 1/8) focused their attention more on the right half of the number line (Figure 1a). The gaze plot revealed their eye movements to go right starting from 1/2.

For the content area of "area/perimeter," gazing patterns of students with different misconceptions were not as unique. For example, in calculating the area of a shape, three groups of misconceptions were identified. The first group can be characterized by student's spatial bias and only searching for the area of the larger, non-grid rectangle. They considered the larger rectangle as the only legitimate area they needed to calculate. Most students (86%) with this misconception were in the same eye-tracking group, focusing their attention on the length and width of the larger rectangle without paying attention to the smaller grid (e.g., Figure 1b). However, students with the other two misconceptions (confusing area and perimeter; misuse of area formula) did not show unique visual patterns. As shown in Figure 1c, students with either of these two misconceptions paid attention to the whole shape, but there were not enough features in their heatmaps or gaze plots that could help distinguish the two groups. More eye-tracking analyses, such as fixation on areas of interest, are still in progress.
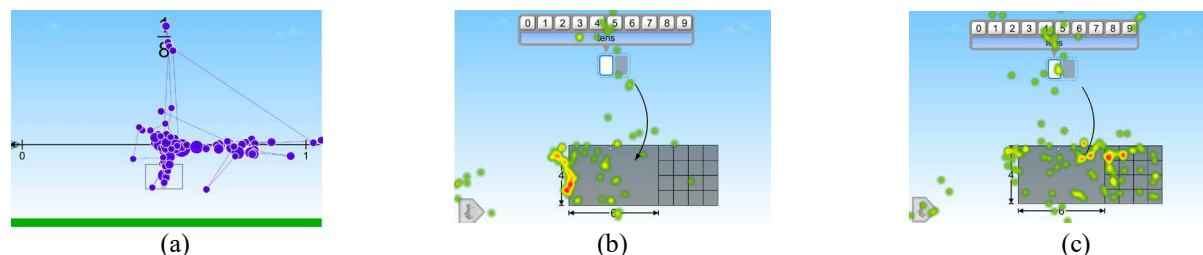

| (a) | (b) | (c) |

Figure 1. Gaze plots for fractions on a number line (a) and heat maps for area/perimeter (b and c).

Discussion and conclusions

Our findings on the correspondence between students' misconception groups and gazing patterns for "fractions on a number line" showed the potential of eye-tracking as a way to diagnose mathematics misconceptions, which if applied, can be used for feedback in real time. In the content area "area/perimeter," eye-tracking data reflected some misconceptions, but were unable to identify other categories of misconceptions. With a bigger sample and more ways to assess these topics, it is likely that visual patterns could be more obvious and generalizable. Another way to obtain more detailed eye-tracking data is to add features in the design of mathematical content (e.g., scaffolding or hints, counting aids, simple calculator) that may reveal more of student's cognitive processes. This qualitative study demonstrated a different approach of gathering evidence of students' misconceptions within digital learning environments. Identifying a more contextual and real-time feedback during the problem-solving process is an important step in designing personalized feedback to support their specific learning needs.

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