Analysing Engineering Expertise of High School Students Using Eye Tracking and Multimodal Learning Analytics

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ABSTRACT

In this paper, we describe results of a multimodal learning analytics pilot study designed to understand the differences in eye tracking patterns found to exist between students with low and high performance in three engineering-related computer games, all of which require spatial ability, problem-solving skills, and a capacity to interpret visual imagery. In the first game, gears and chains had to be properly connected so that all gears depicted on the screen would spin simultaneously. In the second game, students needed to manipulate lines so as to ensure that no two intersected. In the final game, students were asked to position gears in specific screen locations in order to put in motion on-screen objects. The literature establishes that such abilities are related to math learning and math performance. In this regard, we believe that understanding these differences in student's visual processing, problem-solving, and the attention they dedicate to spatial stimuli will be helpful in making positive interventions in STEM education for diverse populations.

Categories and Subject Descriptors

H.5.2 [Information Interfaces and Presentation]: User Interfaces. K.3.1 [Computers and Education]: Computer Uses in Education.

Keywords

Eye tracking, simulations, games, multimodal learning analytics, constructionism, spatial ability.

1. INTRODUCTION

The need to engage and motivate more students to learn science and engineering has raise considerable awareness about Constructionist [9] and project-based pedagogies in classrooms. Understanding students' behaviors and cognitive evolution in these open-ended environments is a challenge that is being tackled in the nascent field of Multimodal Learning Analytics [4, 11]. In particular, this study uses eye tracking to examine students' capacity to interpret visual imagery in the context of engineering problem solving.

Computer-based learning tools such as games and simulations have become pervasive in learning environments. These technologies can be used by learners to improve their cognitive abilities and to acquire specific skills [6], including those involving visuospatial attention and perception [1]. Video and computer games habits have been shown to be related to the improvement of visuospatial abilities, including mental rotation and visual memory. Likewise, the enhancement of performance in visual memory recall tasks has been associated with the duration of game exposure, even when the gender has been controlled [10].

In this paper, our interest is not in the games themselves but in the engineering, mathematical, and problem solving skills required to solve the puzzles presented in the game. Visuospatial abilities are involved in the processes of manipulating spatial forms, and these abilities are associated with different kinds of scientific thinking [12]. Performance in standardized visuospatial tasks has been associated with performance on math evaluation tests as early as primary school [5]. A study with low- and typically achieving students demonstrated that low achievers have poorer overall performance and a higher number of errors in online game-like visuospatial working memory tasks. The same study found that low achievers also demonstrated more errors and higher reaction times for arithmetic tasks [2].

Another study showed that difficulty in manipulating internal and external visuospatial representations are related to conceptual errors in chemistry, even when the problem to be solved is not explicitly spatial. These authors suggest that designing and developing tools and software to train students' spatial visualization capacities may improve their representational and conceptual skills, which should be helpful for learning chemistry. The principles involved in this process include: 1) the provision of multiple representations of the process; 2) ensuring that referential connections between the conceptual elements of the lesson are easily grasped through visual representations; 3) the presentation of the dynamic and the interactive nature of the process; 4) promoting transformations between 2D and 3D representation; and 5) reducing students' cognitive load by making the information more explicit and integrated [12]. Another researcher suggests that manual rotation is also useful to the improvement of the mental rotation skills [11].

Considering these five principles, the present effort presents data from a pilot study (n=7), where students played three online games requiring visuospatial ability in order to explore individual gaze characteristics found to be related to performance.

2. EXPERIMENTAL DESIGN

Seven high school students were invited to play three online games in two separate sessions six days apart. During the first session, they played "Wheels," a game that required them to connect gears and chains until all gears were spinning (Figure 1), as well as "Lines," a game in which they were required to uncross lines until no intersecting lines remained. During the second session, they played "Gears," a second gears game, the object of which was to place gears in specific locations on the screen to set on-screen objects in motion, and they also played the Lines game from the previous session. In each session, they had 5 minutes to play Wheels and Gears and 4 minutes to play Lines.

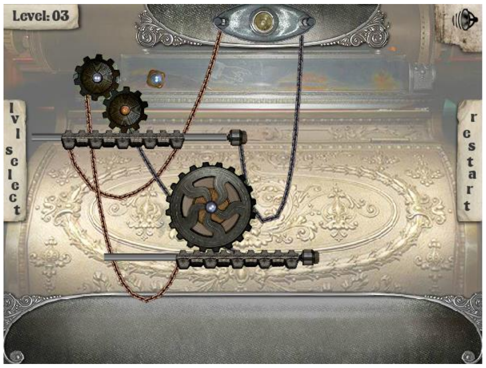

Figure 1: Screenshot of the "Wheels" game.

3. METHODOLOGICAL APPROACH

Since each game was divided into separate levels of increasing complexity, but of brief duration, where only one challenge had to be solved, it seemed appropriate to group the collected data by level in order to gain insight into the strategy used by the learners at each level, as well as the evolution of their strategy during their advancement through the game.

To achieve this degree of differentiation, we wrote a Python script to compute from the collected data the variables that describe a learner's eye patterns at each game level. The variables per student included the number of mouse clicks per level, the time spent on each level, the number and duration per level of unique gaze points, or eye fixations, the direction of the saccadic eye movements (i.e. subjects are moving their eyes from left to right, top to bottom, or any combination thereof), and the type of eye pattern for every trigram, or sequence of three gaze points. Examples of eye patterns of a trigram include when the subject looks right, and then left, and then right again; or when the subject looks up, and then down, and then up again. In the literature such movements are described as A-B-A patterns [10].

To identify differences in eye patterns among the students, a k-means clustering algorithm was performed on the data with variable *k* values.

4. RESULTS

The sample was composed of 4 males and 3 females, and all of them played the games on the same two days. The average level reached during the first session was 5.71 (1.11) for Wheels and 3.71 (0.49) for Lines. The average level during the second session was 8.8 (2.1) for Gears and 3.6 (0.84) for Lines. Since the students had a limited time to play, they were given the option to stop playing at any time for any reason. When they skipped the game, they were led to the next game. Only one student stopped the games prior to completion, and he did so in all of the games. During the first session, he stopped playing "Wheels" at level 4 and "Lines" at level 3. In the second day, he skipped "Gears" at level 9 and "Lines" at level 3.

After performing clustering on the data, we obtained 3 clusters (*k*=3): the first cluster had 2 students, the second, 3 students, and 2 students in the third. The first cluster is composed of the students with the best performance, based on levels reached. This cluster differed significantly from clusters 2 and 3, especially for Wheels (z = 1.15, -0.64, -0.19, respectively) and Gears (z = 0.47, 0.38 and -1.04, respectively). However, the differences were less marked for Lines. During the first session of Lines, there was no difference in performance between clusters 0 and 2 (z = 0.59), although a difference was observed for cluster 1 (z = -0.78). In the second session, no difference was found between the clusters for the lines game.

Taking this in account, we performed analysis on the last game level all students reached on the Wheels (level 4) and Gears (level 6) games to determine whether specific patterns of eye movement at these levels might correlate with overall performance levels. To proceed with the analysis, a new variable defining groups 1, 2 and 3 (corresponding to clusters 1, 2 and 3), was set on the eye tracker software. The goal of this procedure was to identify the visual areas of interest for each group. Figure 2 shows the gaze point clusters for level 4 of the "Wheels" game, which represent the different regions of the screen where the students' vision focused.

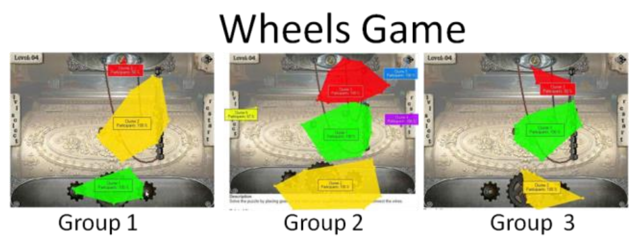

Figure 2: Gaze point clusters for groups 1, 2, and 3 for level 6 of the Wheels game. Each color represents one gaze point cluster: green cluster 1, yellow cluster 2 and red cluster 3.

We can observe a spatial difference between the clusters of group 1, which is the group with the best performance on the task, compared with groups 2 and 3, especially with regard to the screen positions for the first cluster. The first group looked first to the bottom of the screen, where the different gear options were available. The time of the first fixation was 0.52s for group 1, which is significantly shorter than the 6.53s and 1.26s for groups 2 and 3, respectively. Group 1 also used fewer clicks (z= -0.82, 0.17, and 0.57, respectively), more unique fixation points (z= 0.7, 0.34, and 0.19, respectively) and a longer duration on average for each eye fixation (z= 1.05, -0.55, and -0.23, respectively), which can be associated with more engagement and cognitive processing prior to taking action through a mouse click.

For the Gears game, the gaze points clusters for level 6 are shown in Figure 3. Here, we observe a spatial pattern similar to what was found for the Wheels game for the positioning of the first cluster for group 1, as, again, distinguished from groups 2 and 3. All groups showed the first fixation in less than 0.2s. The unique fixation points and the duration of these fixations found for the Gears game followed the same patterns observed in the Wheels game; there were more unique gaze points for group 1 compared with 2 and 3 (z= 0.66, -0.27, and -0.25, respectively) and longer durations on average for each eye fixation (z= 1.16, -0.63, and -

0.23, respectively). The number of mouse clicks for group 1 remained below the average of all students, but higher for group 3 (z= -0.34 and 0.86, respectively), while the number of clicks for group 2 (z= -0.35) was nearly identical to that of group 1.

Figure 3: Gaze point clusters for groups 1, 2, and 3 at level 6 of the Gears game. Each gaze point cluster is represented by a color: green for cluster 1, yellow for cluster 2, and red for cluster 3.

5. CONCLUSION AND IMPLICATIONS

We have presented preliminary results from a study designed to determine how children approach engineering-related tasks embodied in interactive games. This work is situated within a larger research agenda, which is to apply analytics and data-mining techniques for open-ended, constructionist [8] learning activities ("multimodal learning analytics" [4, 10]).

From this small sample, we have observed that students have different eye movement patterns while interacting with the games. Shorter durations for first fixations after a stimulus presentation have been correlated with higher attentional readiness [9] and in this study they were associated with more time spent on the cognitive processing of the task prior to taking action through a mouse click. This pattern may suggest more engagement and reasoning prior to action, which is a valuable skill for students. On the other hand, longer times of first fixations after stimulus presentation, a higher number of mouse clicks, and shorter durations for each fixation point may suggest a "trial and error" approach, where the subject looks for different points on the screen without focusing on strategy or reasoning about the task.

These preliminary results need to be tested with a larger sample and more systematic tasks, but they may point to novel ways of determining students' expertise levels in engineering-related tasks. We believe that those kinds of games can be used as tools for training visuospatial abilities, especially if the task can bring "hands on" elements into mental rotation exercises, as has been done by others researching educational game design [11]. A second issue regarding the development of engineering and science thinking is the use of Bifocal Models [3], where students can undertake computer simulations of tasks through games similar to those that we have presented here, and proceed from that point to the performance of the activity with tangibles objects. Comparisons could then be drawn between the results gathered for the virtual and real undertakings.

We also suggest that further studies take into account ecological variables from the environment to be correlated with performance and eye patterns, such as school performance. A second approach for further studies could be the tracking of eye pattern changes in cognitive tasks after an interventions focusing on skill development.

By identifying elements in students' gaze that were correlated to higher performance in open-ended tasks, this paper contributes to the identification of markers of expertise [4, 10] that might help educators and practitioners learn to detect and assess expertise in unscripted tasks.

6. ACKNOWLEDGEMENTS

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