

An Eye-Tracking Study of GBL Motivators and Learner Behavior

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Abstract: Despite the significant positive characteristics game-based learning offers to pupil learning and assessment, preserving pupils' interest and keeping them engaged in an educational game is still a challenge. To this end, the study and implementation of motivation mechanisms in educational games are considered crucial. Typical examples of motivators in electronic games include points (coins), avatar icons, visualization of achievement levels, NPCs (non-player characters) giving helpful information to users, children-friendly graphics and sound effects, comparison with classmates, and leaderboards. In this paper, we conduct a preliminary study of the effectiveness of these GBL motivators in MG, an educational game for practicing and assessing multiplication skills. The study combined eye-tracking with a short, semi-structured interview session with the four elementary school students that took part in the experiment. Eye-tracking provides detailed monitoring and visualization of gaze behavior in the form of fixation (point and duration of visual focus) and saccade sequences. Given that the way users allocate their visual focus is spontaneous, the data collected and analyzed by eye-tracking are unbiased and give a new spectrum of insight into how users perceive a visual stimulus. In this study, we investigate how users visually respond to the implemented motivators and their visual behavior when deciding between two or more available answers and when given feedback after a wrong answer. The paper discusses useful eye-tracking metrics, provides adequate visualizations of the main findings, and concludes with the ways eye-tracking can help education scientists and practitioners gain a better understanding of the behavior of users of GBL applications and the motivation mechanisms they support.

Keywords: Motivators, Eye-tracking, Total fixations duration, Multiplication, Elementary school, Student assessment

1. Introduction

Motivation has a very important role in learning and achievement and furthermore motivated pupils have better outcomes and perform better (Pintrich, 2003). Motivation can be described as *"a condition that activates and sustains behavior toward a goal"* (Brown, 2007). Motivation can be categorized into intrinsic and extrinsic: intrinsic is produced by internal factors, whereas extrinsic by external factors. Intrinsic motivation exists when a learner has internal desire to perform a task, while will only be rewarded with personal satisfaction and enjoyment (Hodges, 2004). *"Fascination with the subject, a sense of its relevance to life and the world, a sense of accomplishment in mastering it, and a sense of calling to it"* (DeLong and Winter, 2002) are intrinsic motivators. Developing intrinsic motivation leads to student learning while the subject remains in the center of these efforts and not rewards or penalties. Extrinsic motivators exist when a learner is motivated by rewards and incentives external to personal interest and satisfaction (Hodges, 2004). External motivators can be money, prize, grades, positive feedback, the learner's purpose to establish parental satisfaction, the desire for high assessment in an external exam or be best among peers (Ur, 1996; Brown, 2007).

Gamification uses the motivational power of techniques, mechanics, and dynamics of games to support participation, persistence, and achievements. Gamification takes advantage of the combination of both intrinsic and extrinsic motivation: extrinsic rewards for engagement while there are promoted intrinsic motivation features like achieving mastery, autonomy, and sense of belonging (Muntean, 2011). Points, badges, leaderboards, performance graphs, meaningful stories, avatars and teammates are considered to be the game design elements with the strongest effect on motivation (Sailer *et al.*, 2017).

In this paper, we conduct a preliminary study of the effectiveness of gamification motivators in the Multiplication Game (MG), an educational game for practicing and assessing multiplication skills of elementary school pupils (Leonardou, Rigou and Garofalakis, 2019, 2020). In its final development phase (Leonardou, Rigou and Garofalakis, 2020; Leonardou *et al.*, 2022), MG incorporated gamification motivators: points (coins), avatar icon, visualization of level achievements (current and previous), NPC characters giving information, children-friendly graphics and sound effects, social comparison and leaderboards. In the current study, gamification motivators in MG are studied with the help of eye-tracking, which provides detailed monitoring and visualization of gaze behavior in the form of fixation (point and duration of visual focus) and saccade sequences. Given that the way users allocate their visual focus is spontaneous, the data collected and analyzed by eye-tracking are unbiased and give a new spectrum of insight into how users perceive a visual stimulus. In this study, we investigate how

users visually respond to the implemented motivators and their visual behavior when deciding between two or more available answers and when given feedback after a wrong answer.

2. Related work

Mathematics has been a preoccupation of education and pedagogy since ancient times and remains a growing point of interest to this day. It is an essential part of any modern curriculum for developing students' critical thinking and abilities (Shin *et al.*, 2012; Chen *et al.*, 2021; Zhu, Guo and Yang, 2023). In modern times, the goal and implementation of digital technologies is to redefine the roles of the educator and the learner (Chen *et al.*, 2021; Zhu, Guo and Yang, 2023). The utilization of computer technologies for learning and teaching mathematics, naturally, expands the possibilities for student modeling, exploitation of multiple and associated illustrations, dynamic manipulation, and kinesthetic management of what shows on the display. In this context, the added pedagogical value of employing software in mathematics teaching is sought in the structures and relationships that govern students' interactions with digital objects that are designed to be manipulated and favor a variety of interactions between computing tools and all those involved in the teaching practice (Suherman and Vidákovich, 2022; Zhu, Guo and Yang, 2022, 2023). The mathematics that occurs in such circumstances might be regarded as an activity that benefits generative reasoning rather than an established process of implementation of educational materials and instructions. As a consequence, we intend to capitalize on the children's urge for play, helping them to break out from abstract and formal forms of reasoning (Bolden *et al.*, 2015; Hahn and Klein, 2022; Pan, Ke and Xu, 2022). The next issue to address is whether an educational game can respond to these features to form a good instructional support environment. At their finest, games provide an experience with a prominent level of involvement and sociability (Strohmaier *et al.*, 2020; Chen *et al.*, 2021; Hahn and Klein, 2022). To make the shift from traditional teaching to digital game-based learning (DGBL) it is crucial to also support student assessment in the digital environment. In literature, traditional methods of student assessment (SA) are described as self-report surveys, standardized tests, etc. The latest years such kind of methods are widely considered by researchers to cause test anxiety. Furthermore, many times they skip students' thinking processes and are not applicable to assessment in the upper grades' skills. On the other hand, digital game-based assessment (DGBA) offers significant advantages. In (Zhu, Guo and Yang, 2023) characteristics of DGBA studies, as well as the adopted games for SA over the last decade are examined from different perspectives through a systematic review procedure. They found there is a trend towards small sample sizes and that educational games, which are less fun, emerged as the most frequently used game genre. The study of (Chen *et al.*, 2021) investigated the application of game-based learning in science and mathematics education. They found that this application in the particular fields help learners increase their motivation and reduce learning anxiety.

Numerous research efforts have focused on the use of new technologies in the study of cognitive and behavioral/attitudinal change in education and the importance of using non-interventional methods in studies with children. Strohmaier *et al.*, (2020) provide valuable findings that eye-tracking methods are more than beneficial in the studying process, as they help reveal mental representations and assess subconscious aspects of mathematical thinking in students (Strohmaier *et al.*, 2020). Pan *et al.* made a systematic review of learning games foresting mathematics education specified in K-12 settings. They pointed out that there must be improvements in the design of the games (Pan, Ke and Xu, 2022). Another relevant study, in the field of physics education research showed that eye-tracking methods can help researchers understand the way that a physics problem is solved students and how they learn from it (Hahn and Klein, 2022). In (Fulya Eyupoglu and Nietfeld, 2019) researchers studied motivation factors in game-based learning environments by reviewing studies that have implemented and assessed intrinsic motivation in these kind of games.

Zang *et al.* conducted an eye-tracking study with 27 participants were grade seven students and separated in high/low groups based on their background knowledge on a particular scientific subject (Zang *et al.*, 2022). The results showed that high achievement students exceed the other group in terms of performance which was indicated in their visual behavior as their eye-movements were highly correlated with the performance. In the more challenging tasks, the average and total fixation duration metrics were higher in the high achievement group indicating greater cognitive workload, while there was a statistically significant relationship between pupil diameter and visual attention on the corresponding key areas of each task (AOIs).

Yuhana *et al.* investigated a puzzle serious game for the learning assessment of basic arithmetic operations (Yuhana, Sulistyani and Husniah, 2023) with an experiment that recruited thirty five students between the ages of 11-12. The majority of students revealed that they preferred the game to other classical examination methods, with the results indicating that the game met all the pedagogical criteria it incorporates and scored

high on the technical and playfulness criteria as well but a well-designed and implement serious game framework must satisfy additional conditions for students to fully immerse in the game.

Bolder et al. investigated how different representations of multiplication problems affect children's assessment tasks and visual stimuli by recognizing patterns in eye-movements with eye-tracking technology (Bolden *et al.*, 2015). The experimental design included static pictures with variations in type of representation (groups, array, number line), orientations of calculations (traditional, lots of) and whether the picture matched with the dimensions of the calculation (match, above, below). The results from nine youngsters (9-10 years old) revealed a statistical difference in the successful responses across the various presenting methods, with groups and arrays performing superior. Heatmaps revealed that the youngsters with the highest success rate utilized the counting groups approach, the counting axes method in arrays, and the last digit of the number line in number lines.

Conati et al. introduced Prime Climb (Conati, Jaques and Muir, 2013), an educational game for youngsters to familiarize with factorial numbers, and tested it using eye-tracking. This study incorporates different types of adaptive hints (bottom-out, definition, tool) throughout the gameplay experience to evaluate the student's performance, attitudes, and timing in accordance with the hints. The results from thirteen students (grades 5,6) indicate that there is strong positive correlation between attention to hints and correctness of actions, (i.e., game performance without leading to cognitive distraction of players) while fixation time was increased for students in need of help. When the number of fixations was reduced throughout the second part of the game, the timing of each hint was discovered to influence the visual stimuli and concentration capabilities of the users.

In (Hung, Huang and Hwang, 2014), the authors developed a mathematics mobile game based on e-books to investigate how different teaching approaches effect learning achievement. To identify these differences, 69 5th-grade students were divided into three groups based on their learning styles (digital game-based learning, enhanced-technology learning, and traditional) and answered questionnaires on self-efficacy, motivation, and mathematical anxiety prior to and the experiment. The findings revealed that, in comparison to the other two methods, the traditional practices raised students' learning anxiety while simultaneously failing to deliver better learning outcomes. In contrast, DGBL and e-learning techniques were found to have a substantial impact on self-efficacy and a favorable association with learning motivation.

In (Cutumisu *et al.*, 2019) researchers conducted an experiment in which they studied the visual behavior of university students on critical and confirmatory written feedback while they are playing a poster-design digital game. The main hypothesis was that users dwell longer on critical than on confirmatory feedback. The eye-tracking metrics used to evaluate the results were: a) dwell time of participants when feedback revisits were discounted b) mean number of gaze fixations different between valences of assigned feedback c) difference of mean number of feedback revisits between feedback valences of assigned feedback. This paper brings evidence to support the use of eye-tracking for learning processes over behavioral methods alone to investigate feedback processing as well as to understand the precise factors that lead to a deeper processing of critical feedback.

Eye-tracking has been used in various educational settings including architecture for researchers to understand through their students how they perceive the changes in the field of architecture (Rusnak and Rabiega, 2021), in the industry of manufacturing engineering while students and workers communicate in a problem-solving scenario (Vijayan, Mork and Hansen, 2018), and in chemistry to measure students' visual attention while solving word problems in the scenario of blended learning problems (Tucker Blackmon and Castillo, 2019). Besides different educational domains, eye-tracking has also been used for various user groups. For instance, (Chan *et al.*, 2022) investigated whether eye-tracking training can enhance learning and memory of children with learning difficulties as there is evidence that children who received eye-tracking training showed improved attention and inhibitory control. Children who received the eye-tracking training, showed significant improvement in memory and significantly faster learning.

3. Methodology and Purpose

The experiment was conducted at a well-equipped usability engineering lab (University of Patras) and users were recorded while playing the MG with a Tobii T60 eye-tracker, while collected data were visualized and analyzed with Tobii Studio. The eye-tracker is built into a 17-inch TFT, 1280x1024 monitor and offers an accuracy of 0.5 degrees. Four young pupils took part in the experiment, two boys and two girls attending the 2nd, the 3rd and the 4th Elementary School grades. Two of them (2nd grade pupils) were asked to play the multiplication game with all the numbers (multiplications tables 1-10) twice to study whether the game is fun or tiring for players. The other two (3rd and 4th grade) were asked to select and play with just the more difficult numbers (multiplication

tables of 3, 6 and 9 are considered the most difficult). The purpose for this discrimination was to test all pupils at an 'equal' level of difficulty depending on their grade (skills level).

The game that was tested (MG) includes four consecutive levels with a fixed number of random questions, namely level 1 with True/False questions, level 2 with multiple choice, level 3 with drag-and-drop (players match the question with the answer) and level 4 where players must type the answer. Regarding the incorporated motivation mechanisms, players can select an avatar, collect coins when giving a correct answer, and when completing a level can see the progress achieved so far in textual and visual form (smiley faces, simple quantized representations suitable for primary school ages (Bull and McKay, 2004)). When completing a game session, the player can be informed through bar charts about the overall accomplishments (how well they performed in each multiplication table) and a Hall of Fame (leaderboard) is presented with the names of the classmates holding the best scores. During the entire playing process friendly animals are used as NPC characters to inform or give advice to players.

The purpose of the experiment was to gain insights about the following issues and the study focused on qualitative (rather than quantitative) data and analysis given the small number of participants:

- Do pupils focus their attention on certain parts of the screen and are those parts the expected ones for the progression of the game?
- After the completing each game level, do pupils notice the option to be informed about their progress before proceeding to the next level?
- How do pupils visually react to feedback after a wrong answer?
- Do pupils notice their score (coins) and how often they check it when playing the game?

After playing the game, the moderator had a small semi-structured interview with each participant to more accurately understand and more objectively interpret their emotional states (e.g. excitement, stress, competitiveness) and thoughts (e.g. doubt about the correct answer) while interacting with the game.

4. Collected Data and Discussion

From the inspection of gaze plots, heatmaps and cluster plots it is evident that pupils focused their attention to the important (and expected) parts of the screen depending on the level of the game they currently play (the type of questions). For instance, as depicted in Figure 1, both 2nd grade pupils focused their attention to the main elements of the screen i.e., the equation and the answer section. The difference is that the boy also fixated a fair amount of time on his coins area thus demonstrating a more competitive behaviour. Gaze plots specifically revealed that players made many fixations on the area of the equation and even more on the area of answers which denotes cognitive processing (Figure 2). Another general observation is that at level 4 pupils made more fixations on the question area as at this level they had to calculate and type in the answer and not select it from a set of given answers. In addition, they had to drag and drop each ball/answer (on the bottom part of the screen) on the correct basket/question (on the upper part of the screen). Heatmaps and especially gaze plots (and their animated replay) provide another useful insight: we can observe whether they had difficulty deciding what to choose (and in the case of gaze plots we can also see in which order pupils saw the answers).

Observations from the second group of pupils (grade 3rd and 4th) are quite similar but we recorded lower fixation numbers, as pupils are much more confident about the correct answers. Also, they fixated on visual elements on the screens that attracted their interest (such as their avatar, or the NPC and the sports equipment on each scene), which could also be explained due to their familiarity with the main task (multiplication) which allows them to look around the complete scene and elements on the screen. These more skilled pupils (in terms of math) also notice more the option to see their progress after completing each level and their score compared to their peers. Regarding feedback on wrong answers, they demonstrate less fixations with smaller durations as they only need to be reminded of the correct answer and do not try to confirm it by calculating (which seems to be the case for lower grade pupils).

Table 1 depicts the average TFD (Total Fixation Duration) calculated for the defined AOIs of multiplication equation (question), available choices for the player to select (answers) and the score (coins). The value of this metric depends on the level as each levels offers different types of questions in an ascending order of difficulty according to the designers of the game. Still, eye-tracking data reveal a slightly different story as pupils seem to have spent on average more time fixating at level 3 (74.28 sec), then at level 1 (51.26 sec), then level 4 (44.42 sec) and then level 2 (42.61 sec). Based on the type of questions on each level, the hardest type of questions is drag-and-drop where pupils had to match four multiplications with their answer, and true/false questions of

level 1, which comes as a surprise since this question type is considered relatively easy. One possible explanation is that it is the first level of the game and users are not yet familiar with the user interface and the quiz mentality. As observed in Figure 3, players made the most fixations on the question at hand in level 1 (67% of total fixations duration) and level 4 (87% of total fixations duration). This is expected based on the typology of these questions (the player does not need to examine and select available answers).

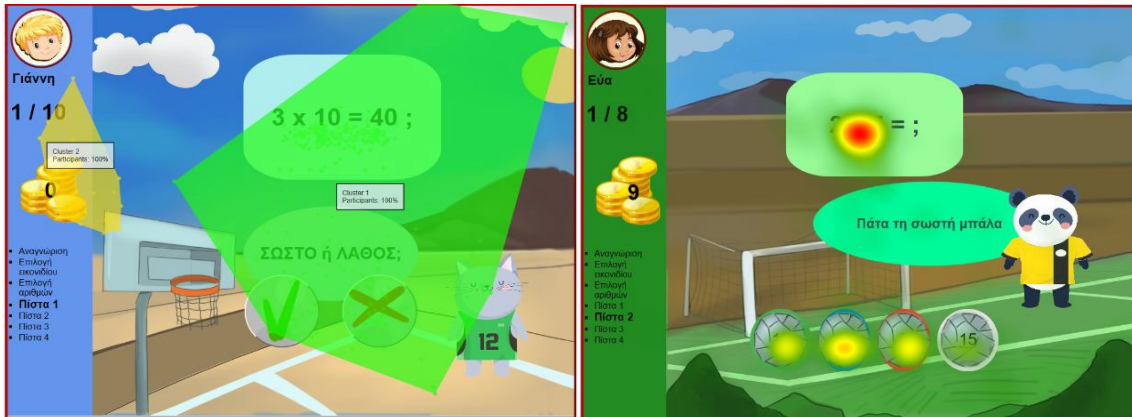


Figure 1: Cluster plot from the boy's interaction at level 1 (true/false) on the left and heatmap from the girl's interaction at level 2 (multiple choice) on the right

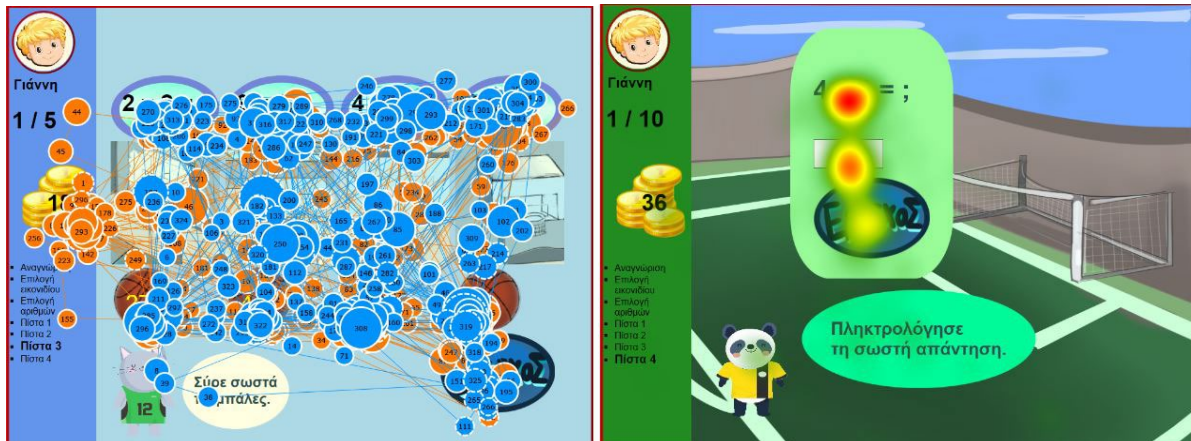


Figure 2: Gaze plot from two game sessions from the boy's interaction at level 3 (drag-and-drop) on the left and level 4 (type the answer) on the right.

Table 1: Average TFD (Total Fixation Duration) for AOIs in each game level

AOIs	Level 1 (true/false)		Level 2 (multiple choice)		Level 3 (drag-and-drop)		Level 4 (type the answer)	
	TFD	%	TFD	%	TFD	%	TFD	%
Equation	34.57	67%	16.66	39%	38.69	52%	38.62	87%
Choice	13.55	26%	23.87	56%	30.99	42%	-	-
Score	3.14	6%	2.08	5%	4.60	6%	5.80	13%
Total	51.26		42.61		74.28		44.42	

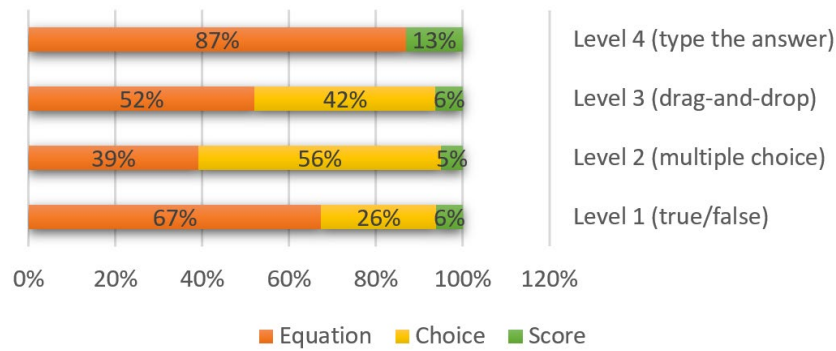


Figure 3: Percentage of TFD on each AOI (i.e., equation/question, choice/answer, and score/coins) per game level

The short interview sessions that followed each eye-tracked game session confirmed that players regardless of age and multiplication skills liked testing their knowledge through the game. More confident players kept their attention to their score and did not need to concentrate much on the feedback when giving a wrong answer, which differentiates them from the less confident players. An interesting observation by the 4th-grade pupil is that he already knew multiplication very well so for him the game did not have much educational value, but he believed that if he could use the game in 2nd and 3rd grade then it would have helped him learn multiplication tables faster. This is an interesting assumption that needs to be confirmed by testing groups of pupils in the 2nd and 3rd grades that will regularly use the game and compare their progress to respective control groups.

Interviews also confirmed that the younger players did get indecisive in certain questions and could not choose between two or three answers, an observation we made based on the eye-tracking data. According to players, the most noticed motivators were the coins, the leaderboard and the NPCs. They also liked the overall design of graphics and embedded sounds but would prefer being able to choose their theme of preference at the beginning of the game. Also, multiplication skilled pupils would like it if a fast correct answer gave them more coins than a slow correct one.

5. Conclusions

The paper presents a preliminary study of the visual behavior of elementary school pupils when interacting with MG, an educational game for practicing and assessing multiplication skills, which incorporates various motivation mechanisms. The purpose of the experiment was to examine how eye-tracking can be integrated into user testing and reveal additional findings regarding specific game design elements and user visual behavior in terms of learning through playing. Findings indicate that pupils noticed, used and liked coins, the leaderboard and NPCs. Eye-tracking offered information about questions that puzzled pupils, pupil behavior towards feedback on wrong answers and level of pupil competitiveness. Overall participants with different level of multiplication skills behaved differently as regards coins and feedback on errors and they also expressed different opinions about motivators when interviewed. This is an issue that should be further investigated to reach solid results that can guide educators and game designers towards selecting and incorporating a suitable set of functionalities and motivators in educational games. Moreover, factors other than skills may affect this decision (such as player gender and personality).

The primary limitation of this preliminary study is that it is based on the observations of a small user group, but it is starting point to prepare for a future expanded test that will include more pupils and a longer testing periods. According to the related bibliography, 39 participants allow for quantitative analysis of collected eye-tracking recordings, but qualitative analysis can be done with less than 10 users. Considering the additional insights eye-tracking can offer, it is a practical choice to incorporate it in user testing even if just for a small subset of the user group.

Acknowledgments

The present work was financially supported by the «Andreas Mentzelopoulos Foundation»

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