Design of adaptive educational games using Eye-tracking for effective personalization of learning

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Abstract

This work studies the integration of adaptive systems, in educational games that use Eye-tracking, to enhance player engagement and learning outcomes. The Eye-tracker allows to collect real-time data on users' gaze and attention. Motivated by the challenges individuals with physical or sensory disabilities face when confronted to computer interactions, we emphasize the potential of adaptive systems using Eye-tracking to facilitate their experience with educational content. Our methodology involves identifying adaptive mechanisms and adjusting them to the Eye-tracking technology. This work also conducted the development of an educational game prototype using the methodology, and within the GazePlay project. Despite the inability to complete the experiment, preliminary insights suggest that adaptive systems aided with Eye-tracking can improve player engagement and learning. Future research should focus on comprehensive experiments to validate and improve these adaptive techniques.

1 Introduction

Study context

This work was done along with the GazePlay project [Schwab, 2016 2024].

When referring to adaptation terms like customization or personalization, one can often confuse a term for another. The present work uses precise definitions of adaptivity and personalization that come from Streicher's book [Streicher and Smeddinck, 2016]: adaptivity is the fact that a system is not fixed, but dynamically changes over time; and personalization is the act of changing a system to the needs of a specific individual user.

This work also comes with its own definitions, indeed the difference between a serious and an educational game may not be grasped by every reader. We will emphasis on the fact that an educational game is a specific type of serious game that focuses on the learning of skills. A serious game is then a subgenre of games that have a primary purpose other than entertainment, used by industries such as defense, education, scientific exploration, health care, emergency management, city planning, engineering, politics, and religion [cs.gmu.edu, 2015].

Motivations

Individuals with physical or sensory disabilities face challenges interacting with their environment on a daily basis. For this reason, they also have trouble interacting with computers and such technology in general. Eye-tracking is a technology that can help the dialogue with non-vocal and physically handicapped people.

The research on Eye-tracking is very active, with related works emphasizing on assessing using visual functions [Lima and Ventura, 2023]. Works that could lead to psychological and neurological tests improvements over traditional methods [Nancy M. Johnson-Martin and Stowers, 1987].

There already exist projects that allow severely disabled people to access educational games using Eye-tracking (i.e. GazePlay [Schwab, 2016 2024]). On the other hand, serious games are also being studied as a therapeutic means to cognitive reeducation using adaptive approach [Dörner *et al.*, 2016]. But there is little to no research on combining the two, that is improving the user experience of Eye-tracking games through the adjustment of adaptive systems.

Overview

"The ultimate goal of an adaptive educational game is to support players in achieving progress towards individual learning goals. Since technical measurement methods for the direct and effective assessment of knowledge gain in the human brain are not available, the evaluation of learning efficiency has to be done indirectly by assessment tests or other forms of interaction or data analysis processes. The idea behind adaptive educational games is that the users experience an increased flow resulting in an increased game immersion, which in turn positively increases the user's intrinsic motivation to interact, play and learn and ultimately to produce an increased learning outcome." [Streicher and Smeddinck, 2016]

Our objective is to effectively personalize the experience and learning of users playing Eye-tracking educational games, by means of adaptive systems. The citation above rephrased, adapting the system to the user is a shortsighted approach that should allow the system to maintain its appealing and its focus to the user. That focus then foresees an emphasis on the user to gain skills required by the game.

This work will start by presenting the measurement instruments, the data collected, and methods to analyse the data, what is treated and how. We will then identify more precisely the needs and learning objectives of an educational game that uses Eye-tracking. Towards the middle section, this work will present state-of-the-art personalization and adaptive techniques, as well as their adjustment to Eye-tracking games. Each technique will be presented with an analysis of their pros and cons, and how the technique relates to moving towards an adaptive system. Finally, prototype results will be compared with the current state of adaptive systems, before jumping to the conclusion.

2 Methodology

Instruments and data collection

Eye-tracking devices measure where and how long a person looks at by capturing eye movements. They typically use infrared light to illuminate the eye, and a camera records the reflections from the pupil and cornea. By calculating the vector between these reflections, the device estimates the gaze direction. The most common method involves remote (figure 1) or head-mounted cameras that track the eyes' movements with high accuracy and high sampling rates.

Any Eye-tracking device needs a calibration phase, since it is essential to map eye movements accurately. This calibration processes an individual's gaze looking at predefined points, allowing the device to create a precise relation between gaze direction and display.

Eye-tracking devices may still differ from one another, and so would the extracted data. We consider the output of a typical eye-tracker to give a sequence of gaze points (that is, coordinates on the screen) with the exception of a special value to describe the absence of gaze directed to the screen (null).

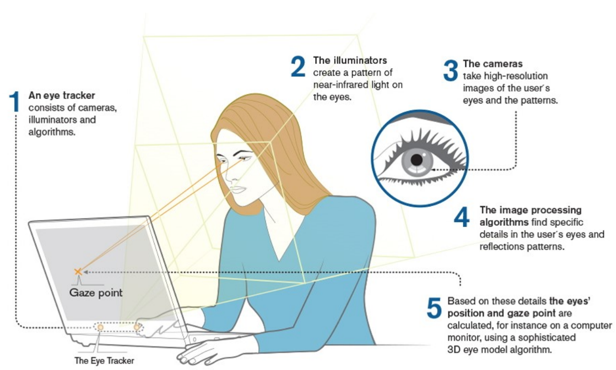

Figure 1: Tobii screen-based Eye-tracker from [Tobii, 2024]

Eye-tracking data analysis

From the raw data can directly be extracted valuable metrics, which are split in 2 categories: interval and event.

Interval metrics are sections of the recording that exhibit importance over some period of time. On the other hand, Event metrics are instants of the recording that mark a relevance of the state.

First, the Area of Interest (AOI) is an object of the scene that may stimuli the user's gaze (see figure 2), it is not data from the instrument itself but rather from the graphical design of the game. The AOI may be part of one's metric or used to trigger events related to a metric.

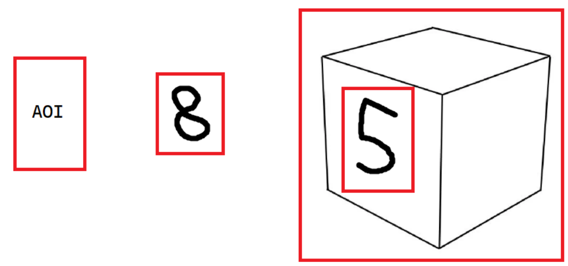

Figure 2: An example scene that has 4 AOIs (in red), an AOI can be inside another one, and does not limit itself to 2D scenes as shown on the cube.

The following non-exhaustive list describes the most important metrics we will cover:

- Fixation, when the eye holds still it creates clusters of gaze points close to each other in terms of time and space.
- Saccade, gaze is not moving as a smooth line, the fovea accelerates then decelerates rapidly to move from one point to another, the saccade is the sequence of gaze points that describe this movement (as seen in figure 3).
- Fixation sequence, which is saccades and fixations alternating into a timeline of fixations points. A sequence of fixations gives the timeline of the attention of the user.
- Time spent, the time of a given fixation a user spent looking at may be useful to track where the attention of the user stepped upon, especially if the fixation is located on an AOI.
- Revisit, when the user keeps coming back to the same AOI, the global time spent in this area increases as well. Revisits are another metric to determine the user's attention.
- Tracking, as opposed to a saccade, is a dynamic (and often slower) translation of the fovea aiming at keeping a target AOI at sight. It can also be defined as a sequence of gaze points that do not form clusters.

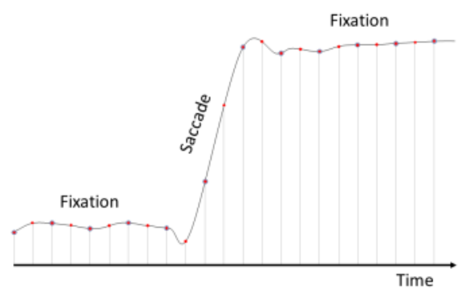

Figure 3: Fixation and saccade, illustrated in 1 dimension by the change of pace between both, from [Tobii, 2023]

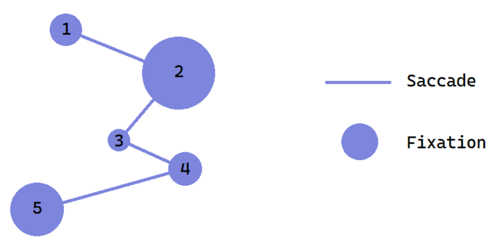

Figure 4: Typical representation of a fixation sequence, the size of one fixation depends on its time spent

3 Design of educational adaptive games using Eye-tracking

Identification of the needs and learning objectives

Maintaining player engagement is crucial, the reason being primarily tied to the effectiveness of learning and the overall experience of the player. Engaged players are more likely to participate actively in the game and sustain their motivation and interest high, which promotes better understanding and retention of the content.

A player with peaking engagement is then said to be immersed. According to Singh, this immersion is ”a desirable outcome for video games of any kind as it leads to higher levels of player enjoyment which in turn leads to players playing the game more enthusiastically and/or for longer periods of time”. Indeed, retaining the player’s attention and enhancing its focus through immersion greatly affects the player’s learning of the content positively.

[Ermi and Mäyrä, 2005] extend the definition of immersion further, splitting it in 3 levels:

1. Level of audiovisual quality and style, where ”good-looking graphics could make the game more appealing, and well-functioning camera angles are associated with good playability”.
2. Level of challenge, which this work focuses on with adaptivity, and where ”the pleasure derived from playing is strongly related to experiences of succeeding and advancing [...]”.
3. Level of imagination, which consists in ”game characters, worlds and storylines being central elements of the game”

The current work emphasizes the use of adaptive level of challenge, but educational game designers must keep in mind those other aspects of their games to maintain player engagement and learning effectiveness.

Estimating the skill of the player is very important to determine whether to adapt or not. Too much challenge for a long period of time and the player is frustrated, not enough challenge and the player is bored (see figure 5). We refer this balance state to the flow experience of [Csikszentmihalyi, 1990], which Csikszentmihalyi describes as the ”holistic sensation that people feel when they act with total involvement”.

But we also need to take into consideration the behavior of the player towards the game, a strategy found and used repeatedly by the player will eventually lead to boredom as well. To prevent this situation we have to change the behavior of the player as often as possible, which we can also do by changing the amplitude or nature of the challenge (see figure 6)

One should first identify parts of its game where adaptivity can occur, and then model how the system should react to the player.

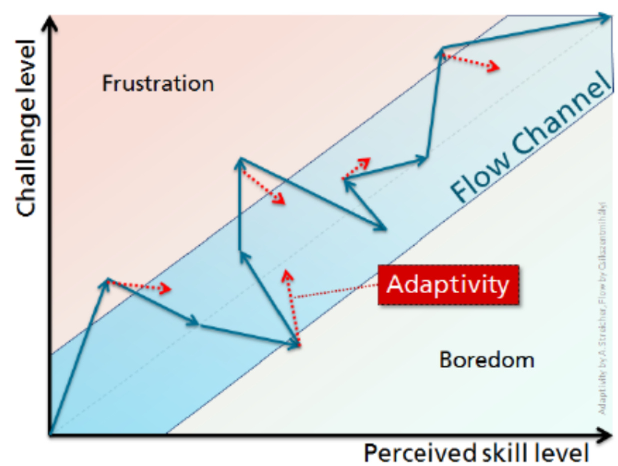

Figure 5: The adaptivity concept of [Streicher and Smeddinck, 2016] applied to the Flow model of [Csikszentmihalyi, 1990].

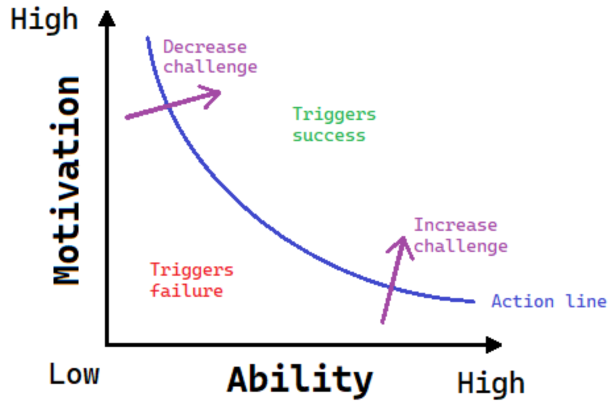

Figure 6: Our application of Fogg's behavior model [Fogg, 2009], the success of triggers for a change of behavior depends on motivation and ability of the individual for the designed task. Adaptivity tries to shift challenge in order to keep the change of behavior of the player.

Adaptive mechanisms for personalized learning content

Adaptive difficulty

Adaptive difficulty, as depicted by [Wikipedia contributors, 2024], consists in changing parameters, environment, or game behaviors in real-time, based on the player's abilities. It is the simplest and most general form of adaptive mechanism, yet widely used across the video game industry. When using Eye-tracking, part of the player's abilities can be perceived through the different metrics we presented previously.

Examples of game elements that can become dynamic using adaptive difficulty, and to which Eye-tracking is a mean of skill perception, are:

- Speed of visual elements, where those visual elements can be defined as AOI, may be measured how well the player perceived them using Tracking.
- Powerups or other spawning mechanics can be optimised to appear at places where the most Fixations were found.
- Artificial Intelligence (AI) of enemies or NPCs could rely on AOI Revisits of themselves or other visual elements to change behavior.

Adaptive difficulty in general can however quickly become too prevalent and exploitable by players who realized its mechanism. Indeed, players can directly fully or partially manipulate the affected game elements by controlling the parameters of the adaptive difficulty system.

Difficulty trials

We also define our own adaptive mechanism to measure player performance. During the game, sets of difficulty trials would be a high increase of challenge for a short period of time or segment, where the reaction of the player to the sudden difficulty is observed and analysed to estimate the player's skill.

A difficulty trial have to not be unfair: there should be no risk (low stakes) so the player does not feel frustration. The trial must also be especially short, or clearly definable to the player, in order to minimize player disturbance. Difficulty trials can target a specific mechanic of the game, or involve the whole game's environment.

Difficulty trials could give more insight about the player's abilities, but should be used with caution because of its proximity with frustrating the player. One should also note that the same problem arise with difficulty trials than with adaptive difficulty: players who discover the mechanism behind difficulty trials can manipulate the adaptive system in a similar manner.

Procedural content

Procedural content consists in computationally produce random game content using algorithms while the player is playing, or beforehand. The main advantage of using this method is the replayability of the content, since it is randomized, the player is less likely to have the same experience with a newly produced game content.

Eye-tracking cannot directly impact such system, but data analysis of the gaze can infer a grasped view of the player's strategies or expectations, which can feed the procedural content algorithm for new and contrasting approaches.

For example, if a player have gazed at large landscapes for extended periods of times, then the game should be more likely to produce new and interesting landscapes for the player to look at. On the contrary, if the player stepped upon small details rather than more global viewing points, the game should take that into consideration as well.

Real-time feedback and assistance

Some generic features are not part of the gameplay, such as in-game hints, but are rather assistive systems aiming at improving the player's introductory experience by showing tutorial prompts or visual/auditory feedback at the right moment.

We can use the gaze to adapt the amplitude of such system: optimizing hints using dependencies between AOI visits, or on the other side not showing hints of features that were already gazed at by the player. Not showing a visual cue as contrasted at peripheral vision than already under the player's gaze.

Although they do not directly impact the gameplay of the player, they make the game handling experience more fluid to the user, which can in turn facilitate player engagement.

4 Prototype of the study

The present work implemented with adaptive systems an already existing educational game that uses Eye-tracking in GazePlay [Schwab, 2016 2024]: "Cups and Balls" consists in a scene of upside down cups with one of them containing a ball, the player is first told which cup contains the ball but must afterwards guess its position.

The game proceeds to a shuffle phase where different actions occur on the ball while the player is a simple observer, the game has notably:

- An exchange action where 2 cups interchange their positions.
- A cycle-like exchange action where 3 cups or more interchange their localization with the next one, the last one going back to the position of the first one.
- Tricking actions, which consist in faking the previously described actions or discreetly moving the ball from a cup to another.

The player then selects a cup, and the game repeats on the next round. The player wins the round if the cup he selected contains the ball. The educational purpose of this game is to teach the player

We first identify which parts can be a model of the challenge, we will here consider dynamic difficulty over rounds rather than in real-time. Among the different gameplay features of the game, we have:

- The speed (or pace) of the animations of the different actions in a round
- The pool of actions which can be used during a round
- The number of cups to display on screen

We can now define the Eye-tracking features and metrics to use as parameters of our adaptive system: Cups will be AOI that tracks whenever the player's gaze is directed over them.

The performance of the player on the speed of animations with a heuristic combining the number of times the player lost track of the cup containing the ball and the player's ability to track the cups during the different animations.

The performance of the player on individual actions will also be computed using the ratio of the number of times the player lost track of the cup containing the ball (only if the cup is involved in the action) over the total number of times this action occurred. Each action will be added or removed to the pool depending on overhaul and individual performance: when all actions of the pool are mastered we can introduce new ones, but if an action is too challenging (due to overwhelming with the other actions, or player disturbance) we simply remove it.

Finally, the number of cups is a parameter the player can choose at the beginning, but it will still change dynamically using the heuristic of the speed performance.

Note that, even if Cups and Balls already exists in GazePlay [Schwab, 2016 2024], we developed it again entirely from scratch in JavaFX, as an alternative version within GazePlay, and under the GNU General Public License. We used Tobii Eye Trackers 5 and 4C for testing, and worked under the Windows 10 operating system in order to use the Tobii Experience software. We also followed code structure and conventions in such a way that the following experiment was easily made possible.

Experiment

We expect to see an increase in attention by the user after applying our techniques to the described prototype. To verify this hypothesis we will run a crowd experiment consisting in the following: split a set of test players in 2 groups as uniformly as possible in age, gender, race and class.

The first group will play the game with all adaptive systems enabled and Eye-tracker, the other group will play the same game without any (thus static difficulty). Participants will not be aware of the difference between both groups, but they will know that their gaze is tracked.

Participants will be told to stop whenever they wish to, and they will be asked later to give their thoughts on their engagement to the game. At last, we will measure the time each participant spent on the game to later plot the results.

5 Conclusion

At the time of writing, we did not conduct the experiment yet, results are still to be determined.

To conclude nonetheless, adaptive systems in educational games with Eye-tracking promise enhancements of the player engagement and learning effectiveness. By adjusting game difficulty and content based on where and how long players look at different elements, we can create more personalized and immersive experiences. Moving forward, more experiments should be conducted to validate these methods and further improve their effectiveness.

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