EyeMath: Identifying mathematics problem solving processes in a RTS video game

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Abstract. Video games are promising tools in educational environments since they have features that can promote learning in a playful environment. Formerly, we identified mathematics learning opportunities in a real time strategy video game. Going further, in order to precisely understand which information the students use to solve the challenges provided by the video game, this paper presents an eye tracker based tool to identify processes of mathematics problem solving while playing the game. The first preliminary results show the potential of the tool to further identify metacognitive and mathematics problem solving processes.

Keywords: Mathematics education, problem solving, eye-tracker, image processing, tower defense

1 Introduction

Video games have appealing features that, at the same time, endow a great potential as instruments for promoting learning and developing specific strategies for knowledge acquisition [1]. In this sense, according to [2], the essential features that endow video games as tools in educational environments are competition, presence of objectives, rules well defined and decision making needs.

From the perspective of mathematics education we realize that video games have not been fully exploited as educational tools. We claim that to full benefit from the most of the characteristics of video games as educational tools we should profit everything that make them attractive and align learning objectives to the objectives of the game. Following this perspective, in an exploratory work [3], we identified mathematics problem solving processes while students, aged from 10 to 12 years old, were playing a real time strategy (RTS) video game of Tower defense genre in which challenges for players constantly arise. In our study we identified that the activity of players includes interwoven problem resolution cycles formed by processes of "Observation - Planning - Decision Making", where mathematical concepts of numerical and geometrical content and functional relation among variables intervene.

Our aim is to precisely understand which information the students use to take decisions, how they take them and which elements are important at each moment. For that, in the former study, to force explicit mentions of the decisions and strategies adopted while playing, students played in pairs. This allows to explore the relation between the discussion and agreements about game strategies the students did and the actions they performed. However, this method is slow and limited. On the one hand, to analyze all the collected data takes a huge time, since each game play took between 26 and 68 minutes. On the other one, the speech of the students is limited due to their age and the nature of the game.

To overcome these limitations, in this paper we propose the use of an eye tracker to create an automatic tool that not only gives the position the player is looking at, but for combining it with the actions taken in the game process itself, reflected in the screen. For that, we create several areas of interest, derived from the previous study, and we intersect them with the gaze of the user. The result is a video of the recorded game play enhancing the area of interest the user is gazing in the screen at every moment. The preliminar results obtained from the analysis of some of these videos show the potential of the proposed tool. We can observe that it either allows the assertion of mathematics learning opportunities previously identified in our previous work [3], or the finding of new learning opportunities that are so intangible to be drawn from the speech recorded while playing.

2 Related work

2.1 Video games as educative tools

Video games have proven to be an educative attractive tool for two main aspects. On the one hand, they are designed from specific rules and objectives. On the other one, the nature of human-machine interaction allows players an immediate response of their actions [4]. In a systematic revision of the literature, the authors in [5] identified those studies that provide empirical evidence of the positive impact of video games on different aspects of school learning. In their work they found evidence of improvement in motor and perceptual skills as well as cognitive skills such as mental rotation, memory or problem solving in a broad sense. The authors in [6] use mini games as a player's challenge to discover or investigate real context details in 3D digital environments.

In the specific field of Mathematics Education there are some studies aimed at determining the impact of the use of video games for learning mathematical content. In the research described in [7] several video games that propose challenges and puzzles to students were used. These video games foster students to work with mathematical content such as numerical sequences, addition and subtraction problems, estimation and recognition of geometric figures. The results of this study show an increase in student motivation during classroom work, showing an increase in cooperation and verbal interaction between students. Also, participating students significantly improved their results in a test of mathematical knowledge to a higher level than students in the control group who did not use video games.

A study [8] analyzing the behavior of students playing some mini games specifically designed for learning mathematics, the author highlights that a key design aspect of these games is the relationship between the game objectives and the learning ones, which usually not match. This fact is supported by the work in [9] that show that one of the main challenges in game design oriented to learning is to integrate or incorporate learning content in the game and its narrative mechanics.

In a recent study [10], the authors used two video games in the same didactic proposal with students of the first courses of primary education. The video games used, *Semideus* and *Wuzzit Trouble*, have been designed from a dynamic visual representation of particular mathematical constructs (the line of numbers and the integer arithmetic, respectively) to build a video game around them. In this way, to solve the puzzles and challenges of the game it is necessary to understand and solve the mathematical problem underlying the raised situation. The results of this study show an improvement in the results about numerical aspects among students who followed the teaching proposal. Meanwhile, the authors in [11] complement this study by analyzing the strategies developed by the students while playing *Wuzzit Trouble*. These authors noted that the video game forces students to constantly review the strategies used, even to develop complex conceptual aspects such as the factorization of natural numbers and combine them to solve the proposed challenges.

2.2 Eye tracking on game-based learning

In the recent years, eye tracking has been used in several fields like psychology, psycholinguistics, visual systems, market research, product design and gaze based interactions [12,13]. In the last years, it has also reached the field of video games with several aims such as interaction tool [14] or evaluation of game experiences [15]. The study of gaze behavior can provide insight about the visual attention of players and thus assist game designers in identifying problems with game play.

Focusing on game-based learning, to the best of our knowledge, the studies done with eye trackers neither go beyond improving the educational games interfaces by means of user experience perception, without forgetting their value to the educative community. The authors in [16] analyzed different attention skills during the interaction of the users with a set of puzzle games. They concluded that gaze patterns allow them to determine some "hot areas" where to put the most relevant contents. The study carried on in [17] explored story comprehension in comic books and video games, finding that comprehension of narrative may be greater in game players than in comic readers. Kiili et al. [18] also claim that eye tracking can provide very deep and objective information about human-game interaction design and layout, although the results interpretation can not be only based on fixation counts and hot spot maps.

We propose going one step further since in our project, the importance lies in extracting information that actually is not directly reflected in eye tracker data. Using image processing techniques and the data obtained from the eye tracker we propose a tool that merge the information given by the eye tracker with the own game solving for simplifying data analysis to identify the mathematical learning processes of the players.

3 External Tools

This section presents the external tools used in this work, the video game and the eye tracker.

The Vector Tower Defense 2. The video game used in the previous and present studies is Vector Tower Defense 2 [19], a RTS video game. The goal is to prevent enemy units (called vectoids), who arrive in waves, from crossing the map. To achieve this, defense towers have to be built to assault vectoids as they pass. Vectoids move along a specific path, and players have a large variety of towers, upgrades and bonus points, boosting them to exploit their strategic skills to the limit. Strategic considerations are based on the choice and placement of the towers and resource management. The game provides the players with many information such as the game map, score, available funds, tower types and their characteristics, like their cost, the damage they inflicts in each attack and their bonus points expressed in percentages.

The eye tracker. The Eye tracker employed in monitoring the player's eye actions is SMI RED 500 by SensoMotoric Instruments [20]. It can be mounted on a monitor size that ranges from 19 to 60 inches and can be controlled remotely from the workstation PC using software provided by SMI.

The SMI iViewX is a software installed on a workstation PC that uses infrared illumination and computer based image processing to calibrate and record eye data. This software remotely controls the eye tracker. It has variable manual calibration and automatic and fast calibration modes.

The SMI Begaze is the software used to replay, visualize, analyze and export raw data recorded with the eye tracker. It has the AOI editor that helps in drawing Area Of Interest points on the gaze replay video and then export data corresponding to the AOIs. Several metrics can be defined to the data sets and the required data sets alone can be extracted. The data exported from BeGaze can then be analyzed for further research.

4 EyeMath: Automatic identification of key game actions

In this section we present the EyeMath, the tool we have developed to contribute to the identification of the elements that determine the type of mathematical learning opportunities when playing a Tower Defense game. Figure 1 shows the pipeline of the process. First of all, the user sits in front of the screen where he/she will play the video game. The binocular eye tracker is placed below the screen. While the user is freely playing the game match, the eye tracker records the fixations, saccades and blinks of the user. Besides, the SMI iViewX collects the data recorded by the eye tracker together with the video of the game match and the positions of the mouse clicks done by the user. After that, an automatic process of the data collected is carried on to analyze what happens in the screen and fuse that information with the actions and fixations of the user. The result is a new video of the game match with the mouse path and the enhancement of the area where the user is gazing at each moment that allow the easy detection of relevant events.

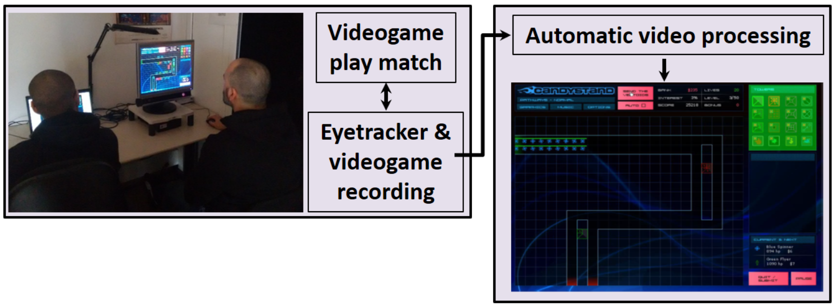

Fig. 1: Pipeline of the resource creation

Eye tracking and game play recording. In the first step a remote eye tracker records eye movements while students play. The eye tracker tracks the eye movements by the infrared light that causes visible reflections in the cornea when it is directed towards the pupil. As we explained before, the software SMI iViewX tracker remotely controls the eye tracker, calibrates the system, and records eye data. It also records screen and mouse click events.

Automatic Data Processing. Once all the relevant data is recorded, the automatic data processing starts. First of all, we split the screen in eight Areas Of Interest (AOI), based on critical times detection in our previous study [3]. These areas are shown in figure 2 and are summarized down below: Send the vectoids button, game details such as lives, money, interest, bonus, etc, tower selection, information about the tower selected, tower upgrade information, tower selling information, current and upcoming enemies information, game play area and background.

From the segmentation of the screen, we create a mask of the AOI and we intersect it with the fixations information given by the eye tracker. In the case of game play area, since it is too large and we are really interested in knowing if the user is looking at the vectoids or not, we create a dynamic mask of the vectoids (whenever they appear in the screen) at each frame by means a background subtraction between the path of a known image without vectoids and the path

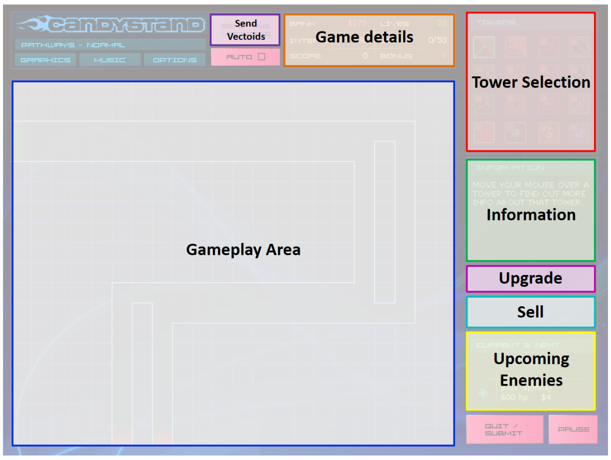

Fig. 2: Screen segmentation in static areas of interest

of the current frame of the video. Figure 3 shows the process of background subtraction of the reference frame and a frame under study. First of all, a mask of the path is multiplied by each frame. The resulting images are subtracted and a convex hull of the result is computed to create the mask of vectoids. This dynamic mask is considered another AOI, so it is added to the AOIs list.

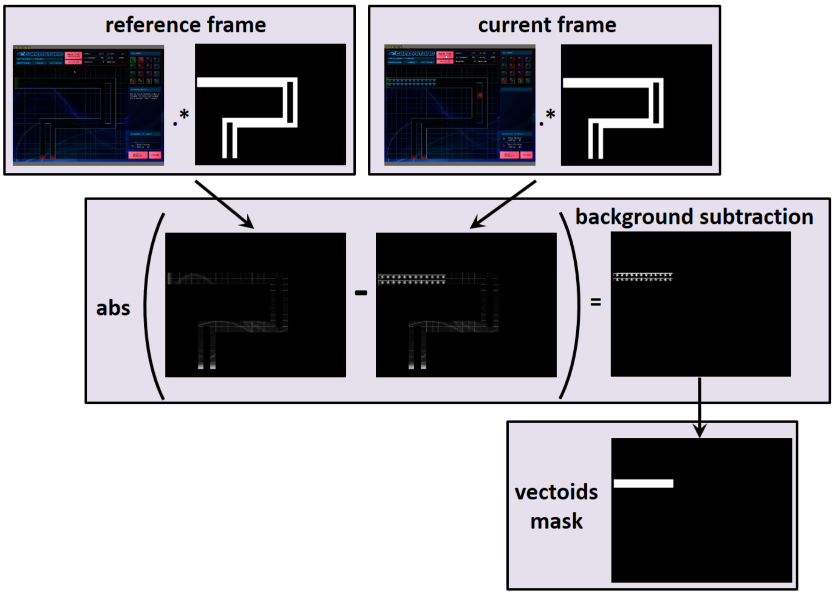

Fig. 3: Background subtraction Process

Finally, at each frame, the gaze of the user is intersected with the corresponding AOI. In the case of game play area, if the user is looking at the vectoids, the former computed mask will be enhanced, but if the user is not looking at the vectoids, it will only be enhanced a range of the eyes position.

Validation. The dynamic mask has been validated by manually labeling 3600 frames as 0 or 1 depending on whether there are vectoids in the screen or not and comparing them with the corresponding automatic output. The results are a 100% of reliability. As well, we have observed the complete resulting videos of 4 game plays and we have compared them to the raw data obtaining also a 100% of true positives. Thus, we can ensure that the tool is robust and reliable, so that it serves to help in the subsequent analysis and identification of mathematical learning opportunities, as we will see below.

5 Preliminar results

In this section we describe the qualitative aspects the EyeMath allows to identify from the observed game plays. In this first approximation, we have analyzed the videos obtained from the game matches of two players aged 13 and 15 years during 37.51 and 34.03 minutes, respectively. In both cases, we recorded the second match they played, since the first time served to show them the game mechanics. As we describe in [3], the process of the Vector Tower Defense 2 is compared to a mathematics problem solving activity, due to the identified processes, the observed complexity and the mathematical content covered. In this way, we appreciate the following findings as problem solving aspects and processes that can be exclusively identified by means of EyeMath.

Data read in the screen. Players read the data with regard to towers and enemies features or play facts (remaining lives, accumulated resources). The identification of that processes should allow to observe differences in the game play between experts and novices players, as well as to observe in which moments expert players need to consult play elements features. These moments indicate the beginning of a reasoned decision making process and an opportunity to learn.

Tower placement and other elements. EyeMath allows an insightful observation of the screen areas where a player is looking at when he/she is taking the decision of placing a tower or using a bonus. In the case of towers, players observe the possible positions and the area that tower covers to determine if it will properly perform during the game. In the case of bonus, they can be placed in the same boxes as towers and affect the towers in a neighborhood of the placed bonus. The player has to decide the optimal position to squeeze its potential and the tool allows to observe in which concrete aspects the player focus on the time he/she is making the decision. Figure 4 shows an example of a decision about bonus placing. In both images, the player is looking (green box) at the borders of the area the bonus covers to decide its optimal position.

Anticipating processes. We observe that players anticipate to the game actions in some circumstances and with different aims. From the point of view of

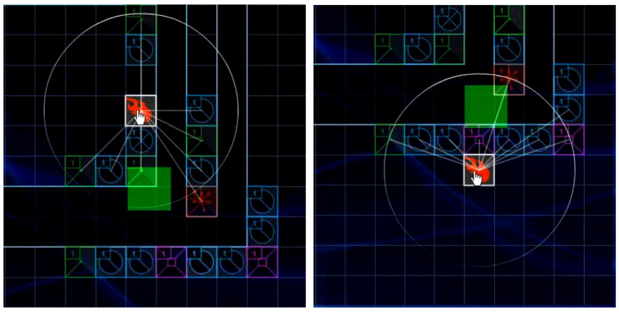

Fig. 4: Example of bonus placement

mathematics learning, this advance denotes the need of achieving data to analyze the play situation. We have observed several types of advance processing:

- Players look at screen areas where there is no tower cover yet, even they do not place any tower immediately after this fixation. We think they evaluate the chances of placing them in a future.
- Players follow the vectoids as they move forward in the screen but they deviate the gaze to the positions the vectoids will occupy in an immediate future to estimate if the placed tower will be enough to kill them. Given the play features, each type of enemy is differently affected by the different types of tower. Thus, the chances of killing the enemies are substantially different in each round. We have observed that novices players do not advance to the vectoids movement in the first rounds but they do as soon as they observe these difficulties. Thus, players intuitively learn that the power of towers depends on their features according to the enemies ones. We consider that this fact could be explicit if there would exist a way of visualizing the amount of damage a tower can causes in each round, e.g. with the inclusion of damage plots. Figure 5 shows an example of an anticipating process. The image on the left shows that the player is following the vectoids, while the image on the right, which occurs 10 seconds later, shows that the player is looking at another area of the path where the vectoids still have to reach.

Decision making in risk moments. In those moments when a situation opposite to the player concerns occurs and he/she needs to react fast, the tool allows to clearly observe the objects the player follows to try to solve the issue. This situation is a clear further learning opportunity since actions taken in these circumstances can not be supported in reasoning, given the short time margin, but they can be mathematically studied later.

Successful play habits. We have observed that both players achieve the habit of checking the available resources and the costs of the next available towers at the beginning of each round. We think that this process of anticipation allows the players to take decisions more effectively and faster in risk moments. From experience failing in these moments due to a bad planning or a lack of crucial

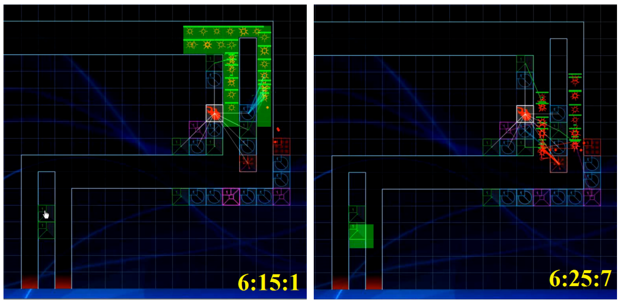

Fig. 5: Example of an anticipating process

information to answer the challenges provided by the game, players ultimately acquire this habit. We think that this process highlight metacognition during the game and it could be exploited in education environments due to its great potential and adaptability in other contexts and circumstances.

6 Conclusions and further work

In this paper we present an analysis tool, the EyeMath, that allows to identify mathematics problem solving aspects in a RTS video game. In particular, we have shown its potential by highlighting, not only some aspects previously identified in a previous work [3], but also some others that hardly will be expressed by players. Consequently, a range of possibilities to analyze processes that could not be analyzed so far opens up. In particular, the EyeMath allows to identify game processes, such as how the users interpret screen data, mathematics problem solving processes, like the way the users place the towers in the field, and metacognitive ones such as anticipating processes. All of them should be further explored since this potential opens the door to understand in more detail the relation between play activity and mathematical content addressed. As well, it should be a key support to determine classroom activities for boosting mathematics work and suggest some new designs for the development of a new educational version of the game.

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