Modeling Visual Attention of Students using Pendulum Problem on Physics Playground

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ABSTRACT
This study modeled visual attention of students as they solved a problem within an educational game for Physics. Participants were given time to view a hint before the static image of the game problem was displayed. Upon viewing the static problem, they were instructed to think of a solution using the hint. An eye tracker recorded eye movement data. After viewing the problem, participants played the actual game level. Gold, silver, or no badges were awarded to the participants depending upon their performance. When analyzing the relationship between the eye movement and performance, the findings are the following: 1) There was a significant difference in the total contact time and number of fixations between participants that had good and bad performance in solving the physics problem on the regions labeled essential to solve the problem. 2) Participants who earned gold, silver, and no badges had different orders of fixating on the regions of interest while thinking of a solution to the PP problem. 3) Participants who had better performance fixated earlier on the regions where the solutions are drawn.

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Categories and Subject Descriptors

• Social and professional topics~Student assessment

General Terms
Performance

Keywords
Attention, Physics Playground and Eye Tracking

1. INTRODUCTION
The "eye-mind" hypothesis describes that the eye-movement is an "on top of the stack" indicator of what information a person is paying attention to and what is being currently processed cognitively [9]. As attention is described as the concentration to one phenomenon while excluding all other stimuli [10][8], this renders it vital in learning. Binder et al discuss that endurance and attention span of students are associated with their performance levels [4]. They showed that sustained attention are linked with accuracy and fluency in learning using curriculum-based measurements [4]. The focus of this study is on attention in the context of learning. Mainly, the investigation was done on the relationship between attention and performance among students using Physics Playground (PP), an educational game designed to help secondary students understand Newtonian Physics [14]. The game aims to help augment the understanding of concepts such as balance, mass, conservation and transfer of momentum, gravity and potential kinetic energy [13]. PP has 80 levels and the goal in each level is to bring the green ball to the read balloon by drawing simple machines such as ramps, levers, springboards, and pendulums. Badges are awarded to the players depending upon the number of objects they have drawn in attempt to solve the problem. A gold badge is given when players solve the level using below or at par with the object count limit set per level. Silver badge is given when players solve the problem but exceeds the threshold. Actions of players are recorded on the background and saved in log files[13].

Different studies on PP yielded different results. While in the US, PP has helped students to have an increased understanding on qualitative Physics[13], in the Philippines however, PP did not result to learning gains [2][3]. Researchers of this study have therefore focused on examining the role of attention (or the lack thereof) among Philippine students that played PP by analyzing their eye movements. Eye-tracking is the method that has been used by researchers to quantify attention relative to the current line of sight of a participant on a given stimulus. This method is generally divided into two major metrics, namely saccades and fixations. Although, saccades are sudden changes of eye gazes between the occurrence of fixation points, no fetching of information happens during this phenomenon [11]. Fixation, on the other hand, is sustained eye gaze at a certain position which indicates a person's intention of what to interact with [16], what is the current task a person is working on [15], and that it is a proxy indicator of attention[5]. Because of this, fixation metrics have been used in conducting the analysis in this study. The questions that the researchers aimed to answer in this study are the following: (1) To what extent can quantify attention of students

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playing PP by using eye gaze? and (2) Is there a relationship between student's eye movement and performance?

2. METHODOLOGY

Note that the entire experiment involved five sets of stimuli. However, the results reported in this paper are limited to the analysis of a single stimuli. Results for the other stimuli and a generalized aggregation of the results are beyond the scope of this paper.

2.1 Participants

A total of 30 high school students were recruited from different parts of the Philippines for this experiment. There were 19 male and 11 female participants, 10 of whom were from Luzon, 11 from Visayas, and 9 are from Mindanao. The mean average age of participants was 15.5 years and participants were in grade levels 9 to 11. Participants typically spent 2.9 hours a day playing video games and 3.6 hours a day watching television. Participants' Physics grades' were 87.9 out of 100 on average. Participants were asked to play the tutorial portion of PP to become acquainted with the game mechanics. After the tutorial, participants viewed static images of a hint and the problem to think of a solution while the eye-tracker was recording their eye movements. Details on this will be discussed in the next section. Participants then played the PP level they viewed. Participants were given a maximum of 3 minutes to solve each level. Finally, participants took a post-test that was isomorphic to the pre-test. Comparison of pre-test and post-test scores showed no improvement after using the PP.

2.2 Material

There were two types of stimuli used in this experiment. The first type in Figure 1 contained the simple machine hint that was most relevant to the solution. The second type was the pre-selected static image of the game level problem from PP named Cloudy Day. Participants were instructed to look at the PP problem at hand while they are thinking of solution of how to bring the green ball to the red balloon by using the hint on simple machine as guide. While they were doing this, the eye-tracker recorded their eye-movements. The regions of interest (ROI) of each stimuli were later defined according to the types described below:

1. Hint - Simple machine hint that was most relevant to the solution
2. Instruction - Instruction about what keys to press to go to the next picture
3. Starting Point - Initial position of the green ball
4. Target - Location of the red balloon
5. Solution Space - Where the simple machine solution is ideally drawn
6. Travel Path - The green ball passes through this area to reach the red balloon
7. Existing Objects - Objects that are not explicitly essential in solving the problem
8. Others - All other regions that have not been defined as regions of interest

There were 2 types of ROIs in the hint, and 5 types of ROIs in the PP level. On the Pendulum hint, the ROIs defined are: 1) R1 – Hint, 2) R2 - Instructions. The static image for PP game level Scale has the following ROIs: 1) R1 – Starting Point, 2) R2 – Target 3) R3 – Solution Space, 4) R4 –Travel Path and 5) R5,R6, R7, and R8 – Existing objects. The regions that were not defined among these categories fell under the "others" classification. These defined ROIs are the essential points of investigation and comparison during the analysis. The ROI definitions on the PP game level were assigned on the basis of where solutions were drawn. Figure 2 shows the solution to the problem. Simple machine pendulum is drawn on R3 to launch the green ball from its initial position to the location of the red balloon.

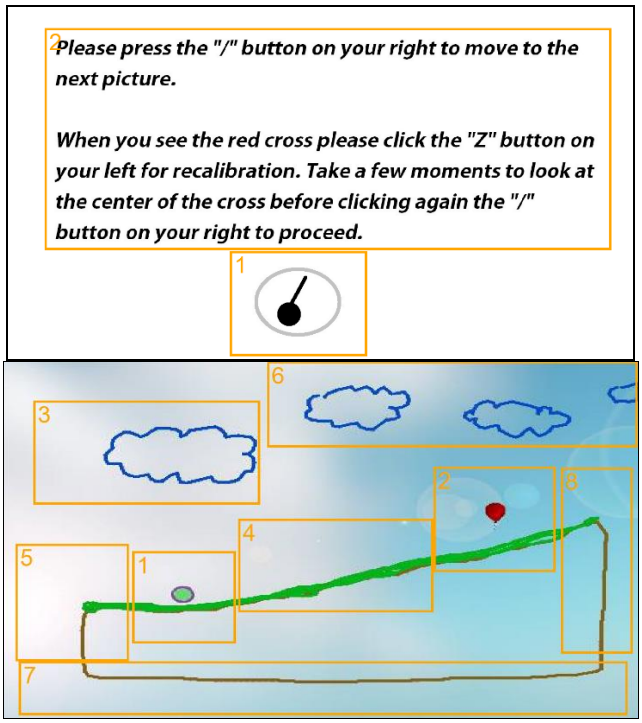


Figure 1. Stimulus 1 on the upper picture is the Pendulum Hint for Stimulus 2 on the lower picture which is the PP game level named Cloudy Day

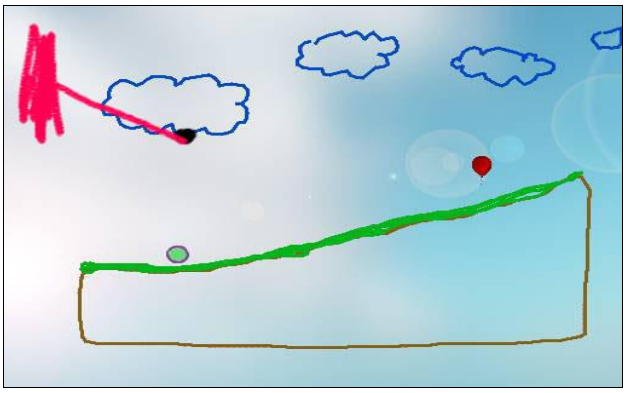


Figure 2. Pendulum Solution to bring the green ball to the red balloon

Table 2. TCT Percentage and Ranking per ROI in Stimulus 2 – PP Game Level Cloudy Day

BADGE	STARTING POING	TARGET	SOLUTION SPACE	TRAVEL PATH	EXISTING OBJECTS				ORDER
	R1	R2	R3	R4	R5	R6	R7	R8	FROM GREATEST TCT
Gold	3 (11.7%)	4 (10.8%)	1 (30.4%)	2 (14.1%)	6 (3.1%)	5 (7.6%)		7 (0.2%)	R3 > R4 > R1 > R2 > R6 > R5 > R8
Silver	2 (17.9%)	3 (13.2%)	1 (33.6%)	4 (7.8%)	6 (3.3%)	5 (4.9%)	8 (0.5%)	7 (0.9%)	R3 > R1 > R2 > R4 > R6 > R5 > R8 > R7
No Badge	2 (17.8%)	3 (17.8%)	1 (18.6%)	4 (16.8%)	6 (1.7%)	5 (4.1%)		7 (0.1%)	R3 > R1 > R2 > R4 > R6 > R5 > R8

2.3 Instrument

The eye movement data were recorded using the EyeNTNU-120 eye tracker that has been used to study visual attention on reading process on integrated circuits in [6] and on how women perceive handbags in [7] . Figure 3 shows the set-up during the data gathering. Participants were asked to place their chins on the chin-rest while the eye-camera was directed at one of the participant's eyes. As the participant viewed the onscreen stimuli, the eye-tracker recorded and mapped participants' eye movements in regions. This device had a sampling rate of 120 Hz and an error rate of less than 0.3 degrees given that the participants were less than 60 centimeters away from the computer screen. The four vital metric variables provided by the system and have been the basis for data analysis are the following:

1. Total Contact Time (TCT) – total time in milliseconds a participant gazed on ROI.
2. Number of Fixations (NOF) –the number of times the participant fixated on ROI
3. Duration of First Fixation (DFF) – the total time in milliseconds that the first fixation on ROI lasted, and
4. Latency of First Fixation (LFF) – the time when the first fixation on ROI occurred.

User eye gaze data and user action logs from PP were later synchronized in order to investigate the relationship between eye gaze data with user performance based on badges earned.

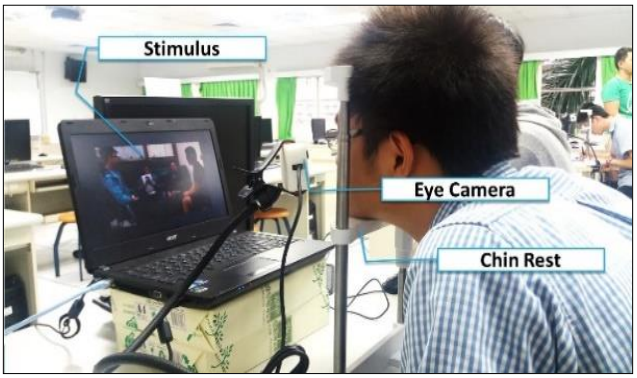


Figure 3. EyeNTNU120 Camera and Chin-rest Set-up

3. RESULTS AND DISCUSSIONS

Out of 30 participants, 20 solved the problem. Six participants earned gold badges and the other 14 received silver badges. Ten participants did not earn any badges. The succeeding sections discuss the analysis of the metric values of the ROIs for both Stimulus 1 and Stimulus 2 and the ROI combinations grouped by badges earned.

3.1 Total Contact Time(TCT)

3.1.1 Stimulus 1 – Pendulum Hint for PP Game Level Cloudy Day

As seen in Table 1, all participants spent more time gazing at R2 – Instructions than in R1-Hint. For R1, gold badge earners had the lowest TCT (7.3%), followed by those who did not earn any badge (23.2%), and those who earned silver badge (21.9%). Gold badge earners had significantly less TCT on R1 than the silver badge earners (t_{16}=2.673 ; two-tailed p=.017). In addition, gold badge earners had significantly less TCT on R1 than those who did not earn any badge (t_{10}=2.339 ; two-tailed p=.0414).

Table 1. TCT Percentage and Ranking per ROI on Stimulus 1

BADGE	HINT	INSTRUCTION	ORDER
	R1	R2	FROM GREATEST TCT
Gold	2 (7.3%)	1 (80.8%)	R2 > R1
Silver Badge	2 (21.9%)	1 (74.6%)	R2 > R1
No Badge	2 (23.2%)	1 (67.6%)	R2 > R1

3.1.2 Stimulus 2 – PP Game Level Cloudy Day

Table 2 shows that all participants had the same TCT ranking for R3 (solution space), R5,R6,R7, and R8 (existing objects) except that only the silver badge earners gazed at R7.

Table 4. NOF Percentage and Ranking per ROI in Stimulus 2 – PP Game Level Cloudy Day

BADGE	STARTING POING	TARGET	SOLUTION SPACE	TRAVEL PATH	EXISTING OBJECTS				ORDER
	R1	R2	R3	R4	R5	R6	R7	R8	FROM GREATEST TCT
Gold	3 (12.1%)	4 (10.3%)	1 (31.1%)	2 (14.5%)	6 (3.2%)	5 (7.5%)		7 (0.3%)	R3 > R4 > R1 > R2 > R6 > R5 > R8 > R7
Silver	2 (19.3%)	3 (12.4%)	1 (32.7%)	4 (8.6%)	6 (3.2%)	5 (4.8%)	8 (0.5%)	7 (0.9%)	R3> R1 > R2 > R4 > R6 > R5 > R8 > R7
No Badge	3 (17.6%)	1 (19.5%)	2 (19.5%)	4 (16.7%)	6 (1.8%)	5 (4.6%)		7 (0.1%)	R2> R3 > R1 > R4 > R6 > R5 > R8

Both gold (30.4%) and silver badge earners(33.6%) had higher TCT at R3(solution space) than those who did not earn any badge (18.6%). While TCT rankings are the same for all participants on existing objects, in ROIs R1(starting point), R2(target), and R4(travel path) the gold badge earners had a different ranking. It is also interesting to note that in all of these three ROIs, gold badge earners had a lower TCT than those who did not earn any badge.

3.1.3 ROI Combinations

Combination of ROIs refer to the average metric values of regions that are essential for solving a level. This result includes the average of R1 from Stimulus 1, and R1, R2, R3, and R4 from Stimulus2. The order of TCT among Badge earners is as follows: SILVER(18.9%) > NO BADGE(18.8%) > GOLD(14.9%). The gold badge earners spent less time gazing at the regions identified to be crucial in accessing information in solving a problem. Gold badge earners had a margin of significantly less TCT on ROI combinations than those who did not earn any badge at all (t_{14}=2.132 ; two-tailed p=.0511).

3.2 Number of Fixations (NOF)

3.2.1 Stimulus 1 – Pendulum Hint for PP Game Level Cloudy Day

In Table 3, all participants had the highest NOF at R2 – Instructions than in R1-Hint. For R1, gold badge earners had the lowest NOF (7.3%), followed by those who did not earn any badge (23.3%), and those who earned silver badge (22.7%). Gold badge earners had significantly less NOF on R1 than the silver badge earners (t_{15}=2.766 ; two-tailed p=.014). In addition, gold badge earners had significantly less TCT on R1 than those who did not earn any badge (t_{10}=2.638 ; two-tailed p=.0249).

3.2.2 Stimulus 2 – PP Game Level Cloudy Day

Table 4 shows that all participants had the same NOF ranking for R3 (solution space), R5,R6,R7, and R8 (existing objects) except that only the silver badge earners gazed at R7. Both gold (31.1%) and silver badge earners(32.7%) had higher TCT at R3(solution space) than those who did not earn any badge (19.5%). Both gold and silver badge earners had the highest NOF on R3.

Table 3. NOF Percentage and Ranking per ROI on Stimulus 1

BADGE	HINT	INSTRUCTION	ORDER
	R1	R2	FROM GREATEST TCT
Gold	2 (7.3%)	1 (82.0%)	R2 > R1
Silver Badge	2 (22.7%)	1 (73.3%)	R2 > R1
No Badge	2 (23.3%)	1 (72.7%)	R2 > R1

It is also interesting to note that R1(starting point), R2(target), and R4(travel path), gold badge earners had a lower NOF than those who did not earn any badge.

3.2.3 ROI Combinations

Combination of ROIs refer to the average metric values of regions that are essential for solving a level. This result includes the average of R1 from Stimulus 1, and R1, R2, R3, and R4 from Stimulus2. The order of NOF among Badge earners is as follows: SILVER(19.1%) > NO BADGE(19.1%) > GOLD(15.1%). The gold badge earners spent less time gazing at the regions identified to be crucial in accessing information in solving a problem. Gold badge earners had significantly less NOF on ROI combinations than those who did not earn any badge (t_{14}=2.438 ; two-tailed p=.0287).

3.3 Latency of First Fixation (LFF) and Duration of First Fixation (DFF)

Figure 4 shows that all participants parsed ROIs in Stimulus 1 in the same manner. That is, based on LFF, first fixation happened in R2 (Instructions), followed by R1(Hint). Table 4 also shows that on average, gold badge earners(48.3 ms) had the longest DFF at R1 followed by silver badge earners(40.1 ms) and lastly by those who did not earn any badge (40.9 ms). All participants had the a longer DFF in R2 than in R1.

Table 5. LFF and DFF Ranking and Time Averages for Stimulus 2 – PP Game Level Cloudy Day

BADGE	METRIC	STARTING POING	TARGET	SOLUTION SPACE	TRAVEL PATH	EXISTING OBJECTS				ORDER
		R1	R2	R3	R4	R5	R6	R7	R8	
Gold	LFF	2 (2.6s)	4 (4.8s)	3 (3.4s)	1 (1.4s)	5 (6.2s)	6 (7.6s)		7 (11.2s)	R4 – R1 – R3 – R2 – R5 – R6 – R8
	DFF	4 (34.7ms)	1 (70.2ms)	3 (35.5ms)	2 (65.0ms)	7 (5.3ms)	5 (33.3ms)		6 (6.2ms)	R2 > R4 > R3 > R1 > R6 > R8 > R5
Silver Badge	LFF	1 (2.4s)	3 (3.3s)	4 (3.3s)	2 (2.9s)	5 (6.8s)	7 (8.0s)	8 (9.0s)	6 (7.5s)	R1 – R4 – R2- R3 – R5 – R8 – R6 –R7
	DFF	5 (35.9ms)	1 (51.0ms)	2 (46.0ms)	4 (39.4ms)	6 (22.3ms)	3 (39.5ms)	8 (7.1ms)	7 (11.9ms)	R3> R1 > R2 > R4 > R6 > R5 > R8 > R7
No Badge	LFF	1 (1.4s)	2 (3.2s)	4 (6.4s)	3 (3.6s)	6 (11.8s)	5 (6.61s)		7 (11.9s)	R1 – R2 – R4 – R3 – R6 – R5 – R8
	DFF	3 (34.6ms)	2 (35.4ms)	1 (38.8ms)	4 (34.4ms)	6 (26.0ms)	5 (26.8ms)		7 (3.7ms)	R2> R3 > R1 > R4 > R6 > R5 > R8 > R7

Table 4. LFF and DFF Ranking and Time Averages for Stimulus 1 – Pendulum Hint

BADGE	METRIC	HINT	INSTRUCTION	ORDER
		R1	R2	
GOLD	LFF	2 (6.2s)	1(1.0s)	R2-R1
	DFF	2(48.3ms)	1(46.3ms)	R2>R1
SILVER BADGE	LFF	2(3.8s)	1(0.4s)	R2-R1
	DFF	2(40.1ms)	1(61.2ms)	R2>R1
NO BADGE	LFF	2(6.1s)	1(0.4s)	R2-R1
	DFF	2(40.9ms)	1(50.6ms)	R2>R1

Figure 4. LFF on ROIs for Stimulus 1 - Hint

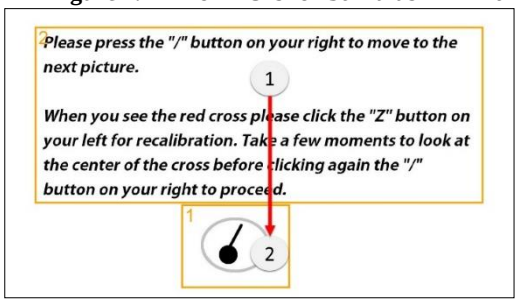


Figure 5. LFF on ROIs for Stimulus 2 – Gold Badge Earners

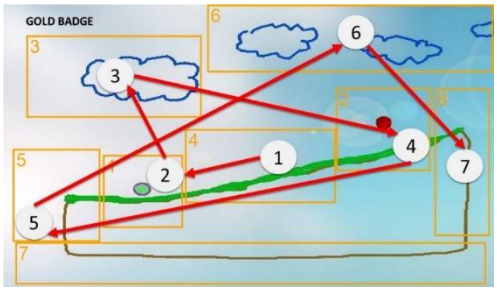


Figure 6. LFF on ROIs for Stimulus 2 – Silver Badge Earners

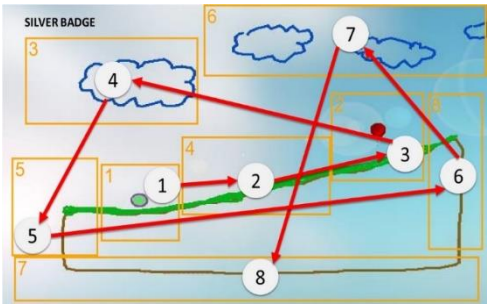
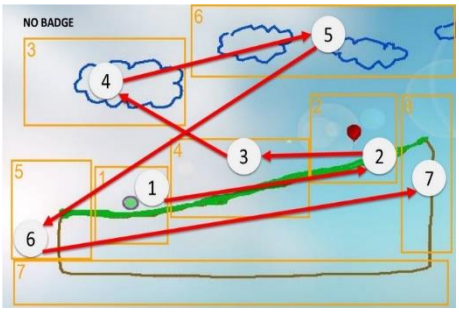


Figure 7. LFF on ROIs for Stimulus 2 – No Badge Earned



Figures 5 to 7 show the LFF of participants that earned gold badges, Silver badges, and no badges. Table 6 shows that these participants all have different orders LFF and DFFs for Stimulus 2. Based on LFF, gold badge earners accessed the region R3 which is the solution space much more earlier, at 3.4 seconds mark, whereas those who did not earn any badge at accessed the same ROI at the 6.4 seconds mark. . Interestingly, gold badge earners accessed the solution space earlier but spent the least time on these spaces themselves. This implies that these participants

arrived at the solutions earlier and faster than those who did not earn any badge.

4. CONCLUSION

Results show that students that had good performance spent less time looking at the stimuli while thinking of a solution. In addition, participants who solved the problem accessed the solution space almost half the time earlier than those who did not solve the problem. These results are indicative that students that earned badges had thought of solution much more faster and earlier than those who did not solve the problem. These findings depart from Binder and et. al [4] who linked that sustained attention to better learning and better performance. Instead, participants in this study accessed the solution space that might have led them to think of a solution more quickly, hence they did not need to gaze at the material for a prolonged or sustained period of time. The researchers suspect that the difference in finding is due to the material and experiment design used. This difference in result is one interesting point for further examination. Furthermore, it is the goal of the researchers to investigate in the future work wether or not a common trend in attention levels of students can be found in other stimuli in PP.

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