ARISTOTLE UNIVERSITY OF THESSALONIKI
FACULTY OF SCIENCES
DEPARTMENT OF PHYSICS

EYE TRACKING AND EYE CONTROL CASE STUDIES IN INTERACTIVE SIMULATIONS

Bachelor Thesis

Didactics of Physics and Educational Technology

Theodoros S. Karafyllidis
SRN: 13924

Supervisor: Euripides Hatzikraniotis, Professor, Department of Physics

Thessaloniki, July 2019

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Examination Date: July 10, 2019

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Abstract

In recent years, eye-tracking has been used in an increasing number of studies on student learning in science. This method is also increasingly being employed to study usability issues in Human-Computer Interaction (HCI) contexts. Accordingly, this study investigated users' eye-gaze behaviors during engagement with computer simulations to answer multiple choice questions, regarding a Physics topic. Four participants were examined and were grouped according to their experience in using computer simulations and their expertise in Physics. Both groups' participants were asked to complete two tasks, where they were given a computer simulation, accompanied by its corresponding worksheet to complete. In each task, the users interact with the simulation in a different way; In the first one, the users controlled the screen cursor using the mouse movement (mouse-control), while in the second one the screen cursor was controlled by their pupil movement (eye-control). During the experiment, a pupil center corneal reflection (PCCR) eye tracker was used to track the participant's visual activity and monitor their actions. After the experiment, each participant was interviewed. The eye tracking results reveal differences between the experienced and inexperienced users' visual activity; In some cases, these differences are suspected to be what led the users to the wrong answers. The results also indicate that despite the fact that users had a hard time using the novel control method to interact with the environment (eye-control), they favor it over the traditional one (mouse-control). Our findings show that eye-tracking is not only a promising technique for conducting educational research but that it can be successfully used as a tool for Human-Computer Interaction, as well.

Περίληψη

Τα τελευταία χρόνια, η παρακολούθηση των οφθαλμών έχει χρησιμοποιηθεί σε έναν αυξανόμενο αριθμό ερευνών για τη μάθηση των μαθητών στις φυσικές επιστήμες. Αυτή η μέθοδος χρησιμοποιείται επίσης όλο και περισσότερο για τη μελέτη ζητημάτων χρηστικότητας στο πλαίσιο της αλληλεπίδρασης Ανθρώπου-Υπολογιστή. Κατά συνέπεια, αυτή η έρευνα μελέτησε την οπτική συμπεριφορά χρηστών κατά τη διάρκεια της εργασίας τους με προσομοιώσεις σε ηλεκτρονικό υπολογιστή, για την εύρεση των απαντήσεων σε ερωτήσεις πολλαπλής επιλογής σχετικά με ένα θέμα Φυσικής. Τέσσερις συμμετέχοντες εξετάστηκαν και ομαδοποιήθηκαν σύμφωνα με την εμπειρία τους στη χρήση προσομοιώσεων και το γνωστικό τους επίπεδο στην επιστήμη της Φυσικής. Οι συμμετέχοντες των δύο ομάδων κλήθηκαν να ολοκληρώσουν δύο δραστηριότητες, στις οποίες τους δόθηκε μια προσομοίωση σε ηλεκτρονικό υπολογιστή, συνοδευόμενη από το αντίστοιχο φύλλο εργασίας της. Σε κάθε δραστηριότητα, οι χρήστες αλληλοεπιδρούν με την προσομοίωση με διαφορετικό τρόπο. Στην πρώτη, οι χρήστες ελέγχουν τον κέρσορα στην οθόνη χρησιμοποιώντας την κίνηση του ποντικιού (έλεγχος μέσω ποντικιού), ενώ στη δεύτερη ο κέρσορας ελέγχεται από την κίνηση της κόρης των οφθαλμών τους (έλεγχος μέσω ματιού). Κατά τη διάρκεια του πειράματος, χρησιμοποιήθηκε εργαλείο παρακολούθησης οφθαλμών τεχνολογίας ανάκλασης στον κερατοειδή χιτώνα (PCCR) για την παρακολούθηση της οπτικής δραστηριότητας του συμμετέχοντα και την καταγραφή των ενεργειών του. Με το τέλος του πειράματος ο κάθε χρήστης απαντάει σε μερικές ερωτήσεις σχετικά με το πείραμα. Τα αποτελέσματα της παρακολούθησης των οφθαλμών αποκαλύπτουν διαφορές μεταξύ της οπτικής δραστηριότητας των έμπειρων και των αρχάριων χρηστών. Σε ορισμένες περιπτώσεις, οι διαφορές αυτές υποψιάζονται ότι είναι αυτές που οδήγησαν τους χρήστες σε λάθος απαντήσεις. Τα αποτελέσματα δείχνουν επίσης ότι παρά το γεγονός ότι οι χρήστες δυσκολεύτηκαν ιδιαίτερα να χρησιμοποιήσουν τη νέα μέθοδο ελέγχου για να αλληλοεπιδράσουν με το περιβάλλον (έλεγχος μέσω ματιού), την προτιμούν έναντι της παραδοσιακής (έλεγχος μέσω ποντικιού). Τα ευρήματά μας δείχνουν ότι η παρακολούθηση των οφθαλμών δεν είναι μόνο μια πολλά υποσχόμενη τεχνική για τη διεξαγωγή εκπαιδευτικής έρευνας, αλλά ότι μπορεί να χρησιμοποιηθεί με επιτυχία και ως εργαλείο για την αλληλεπίδραση μεταξύ ανθρώπου-ηλεκτρονικού υπολογιστή.

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Acknowledgments

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Finally, I would like to thank my students and my fellow students for participating in this research.

Chapter 1

Introduction

1.1 The purpose of the study

Eye-tracking is a technique for collecting data in the context of conducting empirical studies of human perception, cognition, and behavior. As its name suggests, eye-tracking is a means of measuring eye movements to determine where a person is looking, what he is looking at, for how long his gaze is in a particular spot, etc. In turn, locations of visual perception can be used to infer foci and patterns of gaze, as these are relevant to making sense of human cognition and behavior. Several important advancements have occurred in the field of eye tracking in the span of just a few short years and eye-tracking hardware has advanced to the point that the instruments are now mobile so that gaze data can be collected not only in research laboratories but also in the field.

Eye tracking technologies have been experiencing an increasing interest in a broad range of researchers from different backgrounds. Although eye-tracking technology has been used quite widely in cognitive psychology for many decades now, it has only quite recently been employed in the context of conducting educational research. In particular, eye tracking has been used to measure students' visual attention in reading and problem-solving. Furthermore, this technique has been used to study the expertise differences in the comprehension of visualizations. In recent years, it has been used in an increasing number of studies on student learning in science. Knowing where and possibly what students are looking at, as they interact in a designed environment has enhanced micro-level analyses of learning to a level that had not been possible without this multi-modal approach.

The purpose of this study is to show an application of eye tracking in studying student's visual behavior while interacting with computer simulations. More particularly we aim to test the extent of its' use in educational processes. Our main research questions are:

1. Can eye tracking be used to uncover characteristics of the student's behavior while interacting with computer simulations?

2. Can eye tracking be used as an interaction tool between the student and the simulation successfully?

3. Can we detect differences/ similarities in the visual behavior of students with different level of expertise, by using eye tracking techniques?

1.2 The structure of the study

In this chapter, we present the purpose of our study and the reason for choosing eye tracking.

In the 2nd chapter, we present a literature overview of the preexisting work on using eye tracking to study human's perception, cognition, and behavior.

In the 3rd chapter, we describe our experiment's methodology and the materials used to carry it out.

The experimental chapters follow where we display the experiment's results and the conclusions they lead us towards.

In the 4th chapter, we compare our participants' behavior based on their experience in using computer simulations and their expertise in the chosen Physics' topic.

The 5th chapter, we compare a novel method used by the students to interact with the computer simulation, that is moving the mouse cursor with their eyes (eye-control), with the traditional way used (mouse-control).

In the 6th chapter, we study the student's visual behavior and compare it between the experienced/ inexperienced participants to spot the differences. We also compare their visual behavior with the expected one to detect deviations and measure the extent that these deviations can affect the task's success.

Finally, in the 7th chapter, we summarize our findings and conclude with the study's limitations.

Chapter 2

Literature Review

2.1 Eye tracking

Eye tracking is the process of measuring either the point of gaze or the eye movements to determine where a person is looking, what he is looking at, for how long his gaze is in a particular spot, etc. In approaching the topic of eye tracking, we first have to consider the motivation for recording human eye movements. That is, why is eye tracking important? Our eyes are one of the primary tools we use for decision making and learning. It is also said that the eyes are the window to the soul, but they are also the gateway to knowledge about how people gather information and what influences their actions and decisions. We may presume that if we can track someone's eye movements, we can follow along the path of attention deployed by the observer. This may give us some insight into what the observer found interesting, that is, what drew their attention, and perhaps even provide a clue as to how that person perceived whatever scene she or he was viewing (A. Duchowski, 2007). Eye tracking is mainly used for collecting data in the context of conducting empirical studies of human perception, cognition, and behavior, as it can provide authentic information about the learners' behaviors without coding biases. Analysis of eye movements can uncover cognition in humans while performing any task (Merkley & Ansari, 2010). The movement of an eye can be used to understand the cognitive process of an individual (Just & Carpenter, 1976). When properly processed, the eye-tracking results can provide unique insights into students' understanding and reasoning processes, which are otherwise difficult to measure using only survey and interview data (J. Han et al, 2017).

Eye tracking technologies have been experiencing an increasing interest in a broad range of researchers from different backgrounds. Although eye-tracking technology has been used quite widely in cognitive psychology for many decades now, it has only quite recently been employed in the context of conducting educational research. Researchers advocate that there is a relationship between the cognitive process of what we see and our eye gaze movements (Fleisher & Gordon, 2010). Eye-tracking technology has been used to measure student visual attention in reading and problem solving, which has been further analyzed to make inferences on the related cognitive processes (Just & Carpenter, 1980). In recent years, eye-tracking has been used in an increasing number of studies on student learning in science. For example, Chien et al. conducted an eye-tracking study on learning differences and eye fixation patterns in virtual and physical science laboratories. Tai et al conducted an eye-tracking study on how subjects with varying expertise in biology, physics, and chemistry answer multiple choice science questions. The results show marked differences in the ways novice and expert participants processed questions: experts tended to focus faster and spent more time on task relevant details, while novices were more likely to meander throughout the problem. The results show an important link between prior knowledge and visual attention.

2.2 Human-Computer Interaction (HCI)

Human-Computer Interaction (HCI) is a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers. Owing to the rapid technological development, as computers were no longer room-sized, expensive tools exclusively built for experts in specialized environments, the need to create human-computer interaction that was also easy and efficient for less experienced users became increasingly vital. While initially concerned with computers, HCI has since expanded to cover almost all forms of information technology design. As a field of research, human–computer interaction is situated at the intersection of computer science, behavioral sciences, design, media studies, and several other fields of study.

Humans interact with computers in many ways; the interface between humans and computers is crucial to facilitate this interaction. Using the eye as an input method has benefits but also some considerable challenges. While gaze may not be as accurate as an input device like, for example, a manual mouse, if the target objects are large enough, gaze can be much faster at pointing (Sibert & Jacob, 2000). Gaze not only shows where our current visual attention is directed at but it also often precedes action, meaning we look at things before acting on them. Thus, there is a lot of potential in using gaze in human-computer interfaces either as an input method or as an information source for proactive interfaces (Majaranta & Bulling, 2014).

Chapter 3

Methodology

3.1 Materials and Apparatus.

3.1.1 Simulations

Two typical PhET physics simulations (Pendulum Lab and Energy Skate Park: Basics), both focused on the topic of simple harmonic motions, more specifically oscillations, are used for the experiment implementation. In both simulations, the user can set an object (pendulum/ skater) in motion from a specific starting point and observe some Physical quantities (Potential Energy, Kinetic energy, Mechanic Energy, speed, period, etc.) as it performs an oscillatory motion. By manipulating the variables from the control panels, the user can change the object’s mass, the thread’s length, etc. and observe the resulting outcome on the phenomenon and the represented Physical quantities. Also, the user can select which quantities to be represented on the computer screen.

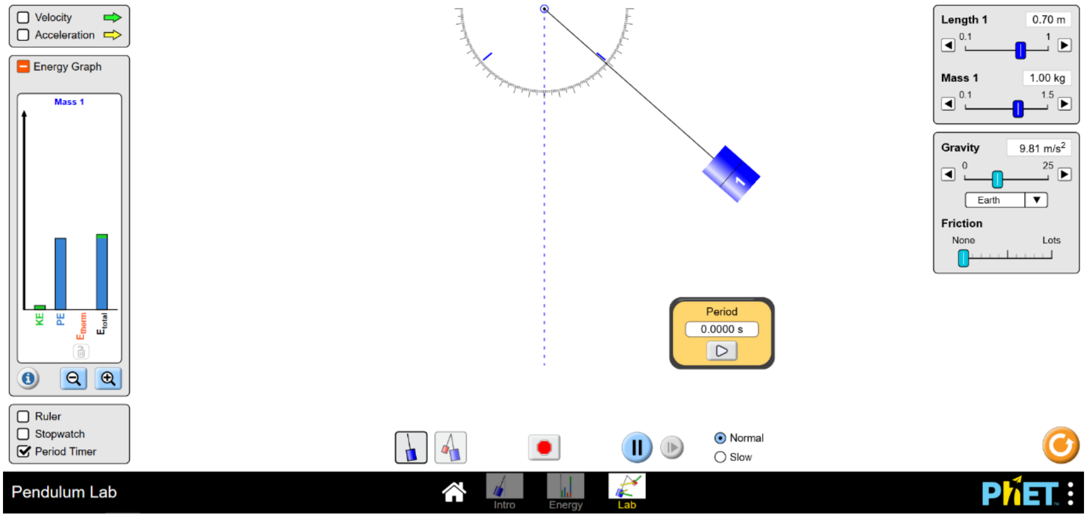


Figure 3.1: *Pendulum Lab simulation.*

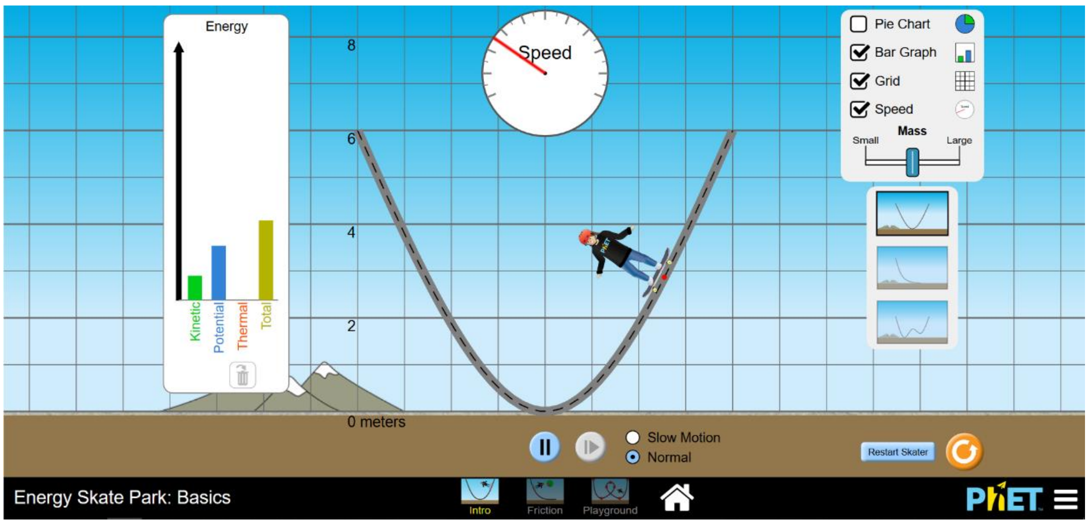


Figure 3.2: *Energy Skate Park: Basics simulation.*

3.1.2 Worksheets

Each simulation is accompanied by the corresponding worksheet (see Appendix). The worksheets are designed to guide the participants during the experiment's process. Both worksheets have the same structure and similar content. In the beginning, there are instructions and details for the experimental process and the simulation's environment. The main body consists of three multiple choice questions. Each question includes two wrong answers and a correct one. In order to answer the questions, the participants must interact with the simulations. Finally, we include some tips and restrictions on the simulation's features that the user should follow.

By reading the instructions, the participants receive information about the object's motion initial conditions (starting height) and which Physical quantities they should select to be represented. They are asked to show the Energy Graphs and the Period Timer/ Speedometer, in order to study the relevant Physical quantities. On the first question, the participants are asked to find the value of a motion-relevant variable (Period/ Speed). On the second one, they should observe the objects' motion and the Energy Graphs in order to find out in which point of their orbit, the Potential Energy reaches its minimum/maximum value. On the last question, they have to make some changes on the object's motion initial conditions (mass/ starting height) and figure out the resulting outcome on the phenomenon and the represented Physical quantities. Lastly, the participants are advised to use the slow-motion option to observe and measure more accurately the Physical quantities and are forbidden to change variables that were not mentioned previously.

The worksheets were designed based on the Predict-Observe-Explain (POE) strategy. The POE strategy was developed by White and Gunstone (1992) to uncover individual students' predictions about a specific event and their reasons for making these. POE is a strategy often used in science. It works best with demonstrations that allow immediate observations and suits Physical and Material World contexts (Chris Joyce, 2006). It can be used for generating investigations, motivating the students to explore a concept, providing teachers with information about student's thinking, etc. Although in our case, we replace the Prediction phase with a Prompt phase, which guides the students in a specific direction regarding the experiment, the Observation and Explanation phases remain the same. Our goal was to see how the participants use the simulation to conduct experiments in order to answer the worksheet questions, paying attention to their visual behavior and not to the learning outcome of the experiment.

3.1.3 Eye Tracker: A Gaze Point 3 eye tracker (Fig. 3.3) with a 60Hz machine-vision camera at the heart of its imaging and processing system is used in order to track the user's visual activity (gaze transitions, fixation points, saccades, etc.) while using the simulations and completing the worksheets. The tracker is placed under the computer screen and before every experiment, it should be calibrated (9-point calibration) to the current user's eye movement.

The tracker collects data of the users' visual activity, such as the x-y coordinates of the fixation point of gaze as a percentage of the screen dimensions, the fixations duration, the mouse cursor position, etc. This data can be later stored in a Microsoft Office Excel Worksheet. In addition, the tracker records the computer screen during the whole process, so that a real-time video can be created, showing the users' actions and overlaying their fixation point of gaze on the image. On this video, we can later create specific areas that contain the necessary information for answering the questions. These areas are called Areas of Interest (AOI) and the tracker can extract special kind of data for these areas, such as how many times these areas are visited, for how long, the time spent on each area compared to that spend on the whole task, etc. Furthermore, the tracker gives the users the option to control the cursor on the computer screen with their pupil movement. Although in order to click they have to use the mouse buttons.

Figure 3.3: *Gaze Point 3 Eye Tracker software.*

3.2 Subjects.

Four participants are examined in this study and are grouped according to their expertise in Physics and their experience in using computer simulations to conduct experiments and solve Physics problems.

The experienced group consists of two senior undergraduate students in the School of Physics at the Aristotle University of Thessaloniki. The first participant is a 24 years old female and the second a 28 years old male. The inexperienced group consists of two 3rd grade students of the Greek middle-school, both 14 years old males. While the experienced users are familiar in working with worksheets and using computer simulations to conduct experiments and solving Physics problems, the inexperienced users have rarely used computer simulations and were never guided by a worksheet to do so. Regarding the topic, the inexperienced users received lectures on oscillations a month prior to the experiment, so they can cope with the experiment requirements.

3.3 Experiment procedure.

Both groups' participants have to complete two tasks. Their job is to use the two simulations to conduct experiments, being guided by the corresponding worksheets, in order to answer its three questions. All participants should complete both tasks on their own. All they have at their disposal is a computer mouse and the computer screen, where they can interact with the simulations and the worksheets. While in the first task (Pendulum Lab simulation) the cursor on the computer screen is controlled with the mouse movement (mouse-controlled case), on the second one (Energy Skate Park: Basics simulation), they move the cursor with their pupil movement (eye-controlled case). Since we do not focus on the learning outcome, no pre/post-test are given to the participants.

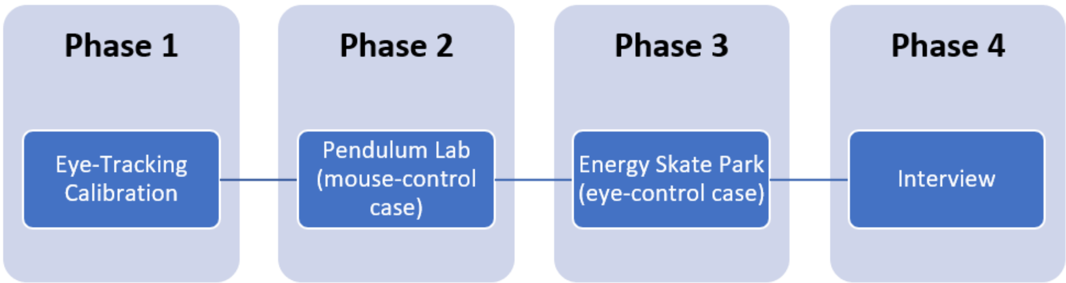


Figure 3.4: *The four phases of the experiment procedure.*

The experiment procedure consists of four phases, as outlined in Figure 3.4. In the first phase, we give some information to the participants about how eye tracking works and we calibrate the tracker to the current user. Then in the second phase, the first task's simulation (Pendulum Lab) along with the corresponding worksheet are presented to the participants at the same time. The simulation is placed on the left half of the computer screen and the worksheet on the right. In this task, the user controls the cursor on the screen with the mouse movement (mouse-control). The participants are encouraged to begin, but without any specific prompt where to start from. They can spend as much time and perform as many trials of the experiments as they want. No formal instructions should be given during this phase except for technical support, whenever needed. The second phase ends with the first task completion and we proceed to the third phase. Firstly, we inform the users about the new method of controlling the cursor. In this case, they move the cursor with their pupil movement (eye-control) however, they have to click the traditional way. We fix the mouse to the table so they cannot move it but still use the buttons to click. Then the second simulation (Energy Skate Park: Basics) is presented to the participants along with its corresponding worksheet, at the same time. We then follow the same process as in the previous case. After the participants complete the second task, we proceed to the fourth phase where the participants get interviewed in order to express their thoughts about the whole experiment's process, the difficulties they faced, the differences between the control methods, etc.

Chapter 4

Experiment’s sub-phases time consumption

4.1 Introduction

The process that individuals follow in order to solve a problem, differs from one to another. Their behavior when facing a problem, depends on the problem itself, on their experience in problem-solving, on their knowledge on the problem’s nature and on many other factors like age, sex, nationality, etc. For example, individuals with higher expertise on the problem’s context and/or more experience in problem-solving, are expected to solve the problem faster and more efficiently than the less expert and experienced ones. The same applies to students when facing Physics problems, as well. We hypothesize that students with higher expertise on a Physics topic and more experience in using computer simulations would need less time to familiarize and use a simulation, in order to answer questions regarding the corresponding Physics topic.

In this chapter, we compare the time experienced/ inexperienced participants spend to complete two tasks that require to use a Physics computer simulation, to answer the corresponding worksheet’s questions.

Our goal is to study:

1. If inexperienced users spend more time to familiarize with the computer simulation, compared to the experienced.

2. If inexperienced users spend more time to use the simulation to answer the worksheet’s questions, compared to the inexperienced.

3. If both types of users spend less time to familiarize with the simulation than to use it to answer the worksheet’s questions.

4. If the users’ experience affects the way they spend their time on the worksheet’s questions.

4.2 Experimental procedure

In our study, we examine four students, grouped into two groups, based on their experience in using computer simulations and their expertise in Physics. All of the participants complete two tasks, where they use computer simulations to conduct experiments, being guided by the corresponding worksheets, in order to answer questions regarding a Physics topic. The experimental procedure is described in detail in the Methodology (Chapter 3).

The two tasks’ implementation corresponds to the experiment’s phase 2 and 3. The experiment’s second phase begins when the first task’s simulation (Pendulum Lab) and the corresponding worksheet are presented to the users.

We split the second phase into two sub-phases. The first one is called the 'familiarization' sub-phase. During this subphase, the users are introduced to the simulation and getting comfortable with it. They follow the worksheet's instructions in order to prepare the environment and define the object motion's initial conditions. This sub-phase ends when the users finally set the object in motion and the second sub-phase called 'working with simulation' begins. During the second sub-phase, the users interact with the simulation to conduct experiments, in order to answer the worksheet's questions. This sub-phase ends when all the questions are answered. We record the time each participant spends on the whole phase, as well on each sub-phase respectively. In the third phase (Energy Skate Park: Basics simulation), we follow the same process as well. We split it into two sub-phases ('familiarization', 'working with simulation') and record the amount of time the participants spend on each one. Furthermore, we split the 'working with simulation' sub-phases in Phase 2 and Phase 3 into three parts (Q1, Q2, Q3), each one dedicated for a worksheet question and once more we record the time the participants devote to each one.

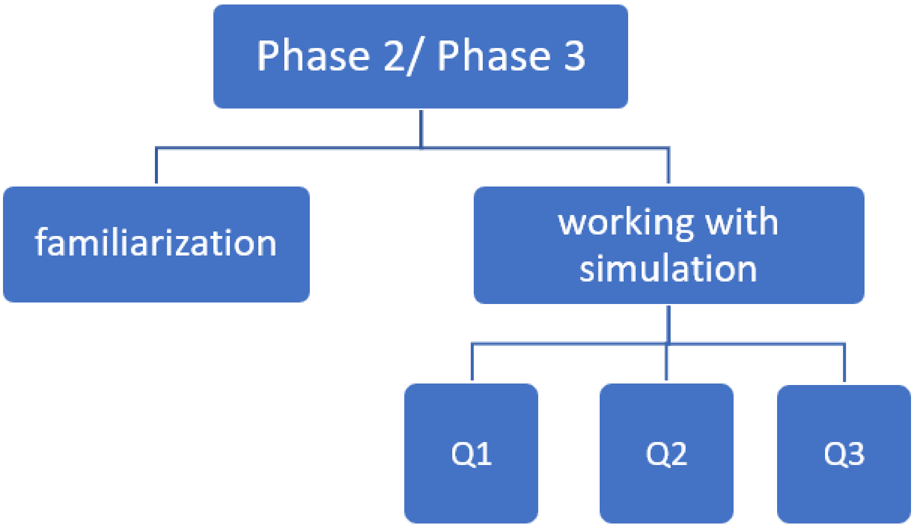


Figure 4.1: *Phase 2 and Phase 3 sub-phases.*

4.3 Results

4.3.1 Familiarizing with the simulation

The amount of time spent by experienced/ inexperienced students to familiarize with the simulation is expected to differ from user to user, depending on the points of interest, the type of exploration and the users experience on using simulations.

For both tasks, we compare the amount of time experienced/ inexperienced users spent on the 'familiarization' sub-phase (Fig. 4.2). Our goal is to find out if any of the two groups spend more time to familiarize with the simulation.

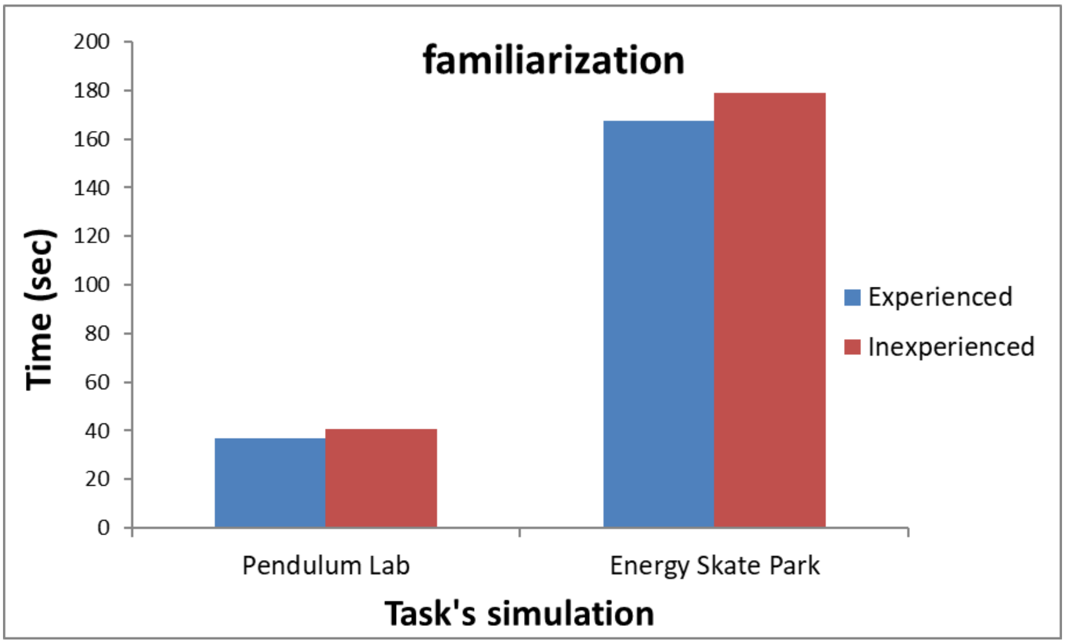


Figure 4.2: *Time spent on both tasks' 'familiarization' sub-phase by experienced/ inexperienced users.*

In our research, we do not observe any particular trend between experienced and inexperienced users. Both types of users have spent almost the same amount of time on average, for the 'familiarization' sub-phase, in both cases (Pendulum Lab: experienced: 37s /inexperienced: 40s – Energy Skate Park: experienced: 168s/ inexperienced: 179s). Therefore, we conclude that the amount of time that users spend to familiarize with a simulation does not depend on their experience. However, this result is limited by the small number of our observations and should be verified by further research.

4.3.2 Working with the simulation

We also compare for both tasks the amount of time that experienced/ inexperienced participants spend working with the simulation, in order to find the answers to the worksheet's questions. The amount of time experienced/ inexperienced users spend on this sub-phase is also expected to differ between the two groups, based on their experience in using simulations and their expertise in the Physics topic. Our goal is to find out if any of the two groups spend more time using the simulation to complete the corresponding worksheets compared to the other.

Figure 4.3 depicts the amount of time experienced/ inexperienced users spent on the 'working with simulation' sub-phase for both tasks.

In the Pendulum Lab simulation's task, the amount of time participants devote to the 'working with the simulation' sub-phase, clearly depends on their experience. Experienced participants have spent significantly less time on average, almost half the time than the inexperienced ones did (experienced:

139s /inexperienced: 251s). On the other hand, in the Energy Skate Park simulation's task, all the participants seem to spend approximately the same amount of time working with the simulation (inexperienced: 157s/ experienced: 151s). Therefore, no clear trend was observed for experienced vs. inexperienced users in this task.

We conclude that the time that users spend to work with the simulation depends on their experience, but this is not the only determinant.

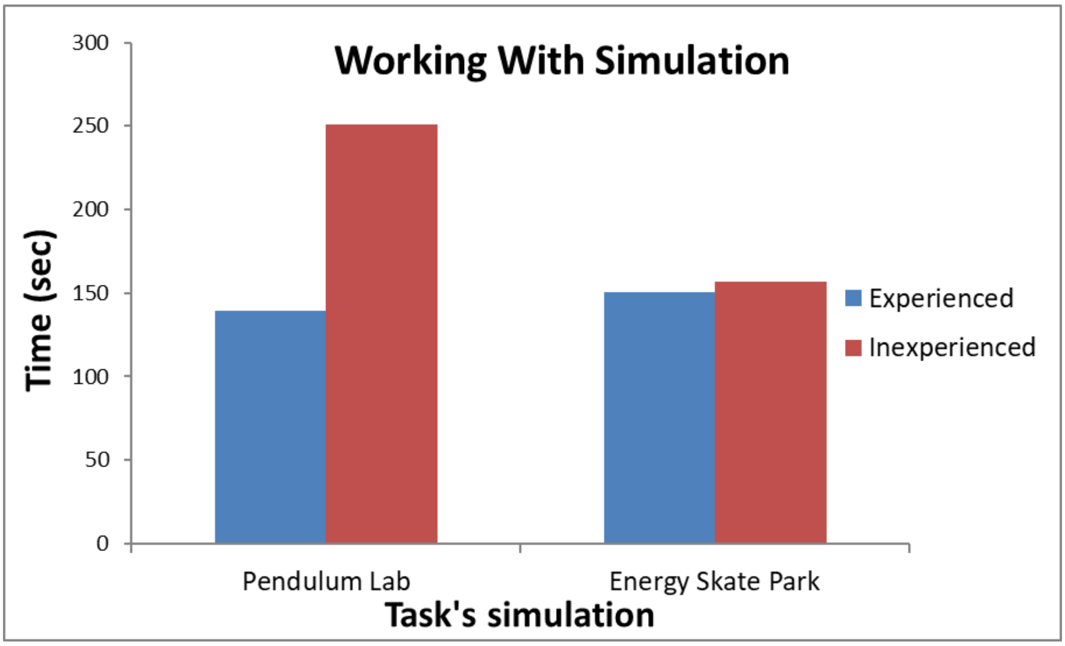


Figure 4.3: *Time spent on both tasks' 'Working with Simulation' sub-phase by experienced/ inexperienced users.*

4.3.3 Task's sub-phases comparison

Except comparing the amount of time spent on each sub-phase separately, between the two groups (experienced/ inexperienced), we also compare it between the sub-phases ('familiarization'/ 'working with simulation'). Our goal is to find out if the participants spent more time familiarizing with the simulation or using it to answer the worksheets questions.

4.3.3.1 1st task's sub-phase comparison

Figure 4.4 depicts the amount of time spent by experiences/ inexperienced users on the 'familiarization' and 'working with simulation' sub-phases, in the first task.

Clearly, the amount of time both groups spent using the simulation to answer the worksheet's questions is way larger than that spent to familiarize with it (Experienced users: 'familiarization' 37s – "working with simulation' 139s / Inexperienced users: 'familiarization' 40s – "working with simulation' 251s). We can better understand the importance of this result, if we compare the amount of time spend on each sub-phase, relatively to the whole phases' duration. The time experienced users spend working with simulation is not even the one-fourth of the whole phase's duration ('familiarization': 21% / 'wws': 79%). Especially for the inexperienced users, this difference is even more significant, as the time spent on the 'familiarization' sub-phase is six times lower than that spent working with the simulation ('familiarization': 14% / 'wws': 86%).

We conclude that both experienced/ inexperienced users spent very little time familiarizing with the simulation than using it to answer the worksheet questions.

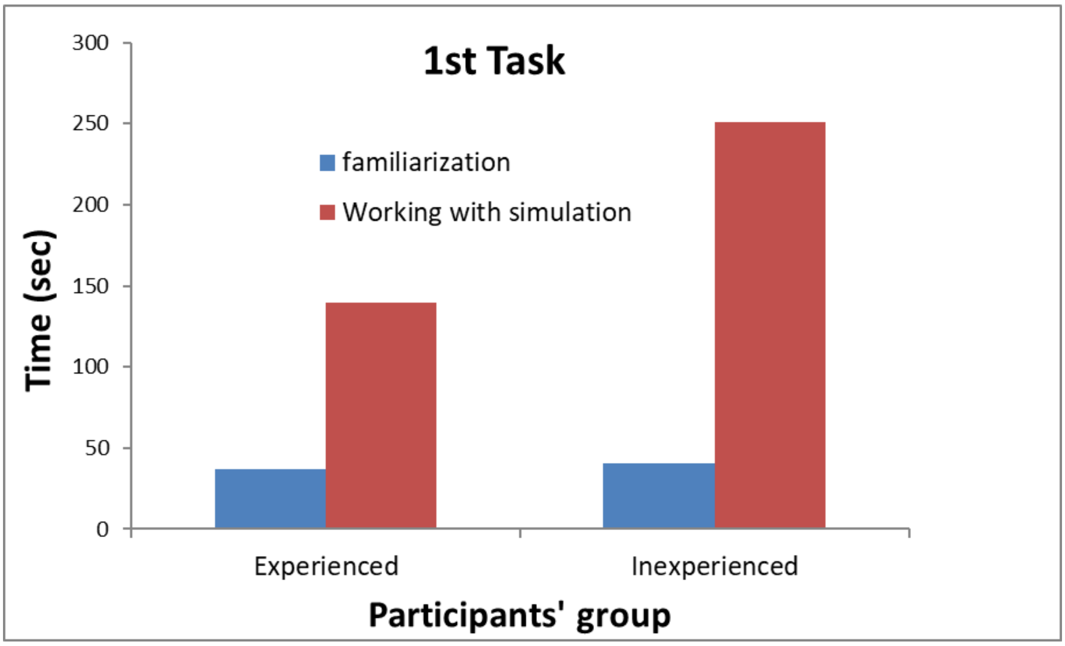


Figure 4.4: *Time spent on the 'familiarization' and 'working with the simulation' sub-phases in Pendulum Lab simulation's task.*

4.3.3.2 2nd task's sub-phase comparison

Figure 4.5 depicts the amount of time spent by experienced/inexperienced users on the 'familiarization' and 'working with simulation' sub-phases for the second task (Energy Skate Park)

In this task, we observe quite the opposite of what we did previously. Here we see that both types of users spend more time familiarizing with the simulation, rather than using it to answer the worksheet's questions (Experienced users: 'familiarization' 168s – "working with simulation' 150s / Inexperienced users: 'familiarization' 179s – "working with simulation' 157s). Although, in this case, the time each user spends on the two sub-phases is quite close to each other. By comparing the time spent on the two sub-phases, related to the whole phase's duration, we do not observe the same significant differences as in the previous task. It is impressive how the time spent on each sub-phase, is exactly the same between the two groups ('familiarization': 53% / 'working with simulation: 47%).

We conclude that the way users decide to spend their time familiarizing with the simulation or using it to answer the worksheet's questions, does not depends solely on their experience, but on the simulation itself, the worksheet's content, the method of interacting with the simulation, etc., too. We study these factors in the following chapter.

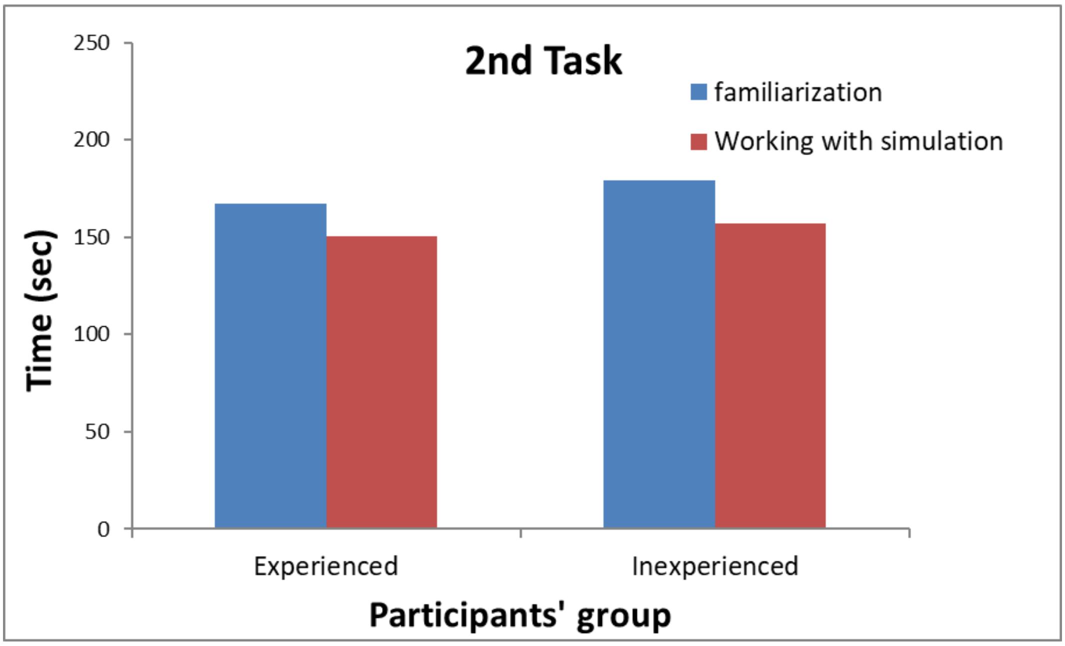


Figure 4.5: *Time spent on the 'familiarization' and 'working with simulation' sub-phases in Energy Skate Park simulation's task.*

4.3.4 Worksheet's question analysis.

The worksheet's main body consists of three multiple choice questions. To complete the 'working with the simulation' sub-phase, the users have to answer all three of them. Therefore, for both cases, we further split the "working with simulation" sub-phase into three parts (Q1, Q2, Q3), each one dedicated to a worksheet's question. Then we record and compare the amount of time the participants spend on each worksheet's question. Our goal is to study in which question do the experienced/ inexperienced participants spend the most/less of their time, to compare each question's duration between the two groups and finally seek for patterns in the way that the users spent their time on the three questions.

4.3.4.1 Pendulum's Lab simulation's questions

Figure 4.6 depicts the amount of time spent by experienced/ inexperienced users on each question of the 'working with simulation' sub-phase, in the Pendulum Lab simulation's task.

Inexperienced users seem to spend more and more time on each question, as they go on completing the worksheet, with the last question consuming more time than the other two combined (Q1: 24s / Q2: 75s / Q3: 153s). On the other hand, experienced users spent a similar amount of time on all three questions, with the first one being the quickest and the second one being the most time-consuming (Q1: 19s / Q2: 71s / Q3: 50s).

Therefore, no particular trend was observed on how experienced /inexperienced users spent the time on the three questions.

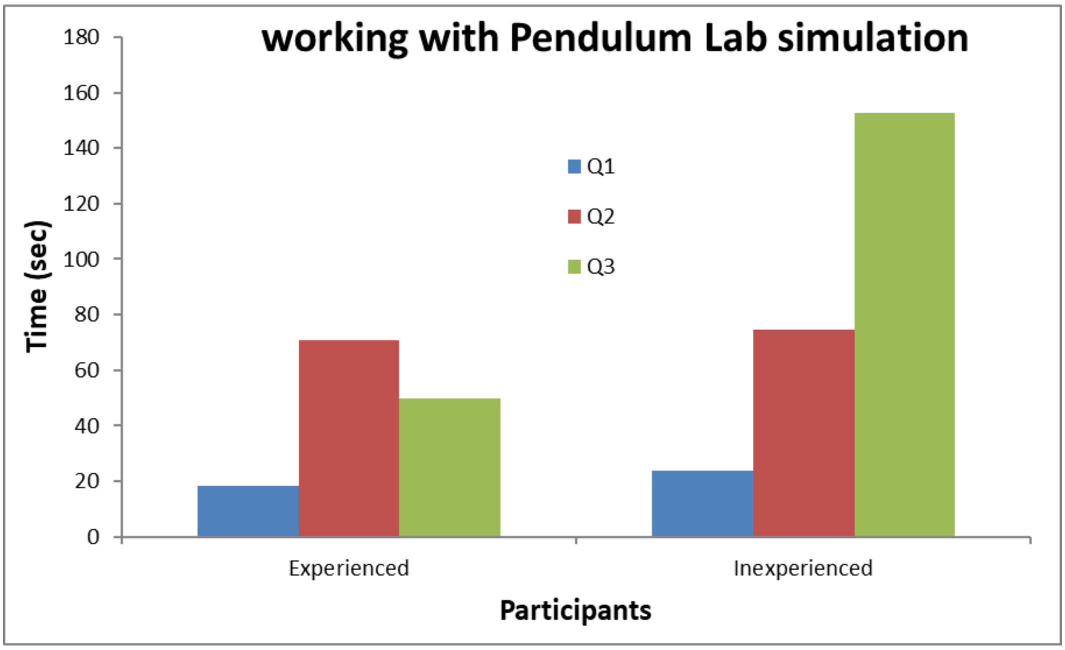


Figure 4.6: *Time spent on each worksheet's question of the Pendulum Lab simulation's task.*

Figure 4.7 compares the time experienced/ Inexperienced users spent on each question of the Pendulum Lab simulation's task.

Comparing the time spent on each question between the two groups we see that both types of users devote almost the same amount of time on the first question (experienced: 19s/ inexperienced: 24s). The first question is also the one where both groups spend the least of their time on (experienced: 13%/ inexperienced: 9% of the whole sub-phase duration). Both groups also spend approximately the same amount of time on the second question, too (experienced: 71s / inexperienced: 74s). However, on the third question, we spot a significant difference between the amount of time the two group's participants spend (experienced: 50s / inexperienced: 152s). Inexperienced users spend most of their time in this question, while experienced users spend less than half of it (experienced: 36% of 'wws' duration/ inexperienced: 61% of 'wws' duration). Therefore, we conclude that the time users spent on the worksheet's third question depends on their experience and is the question responsible for the difference between the users' behavior on the whole 'working with simulation' sub-phase.

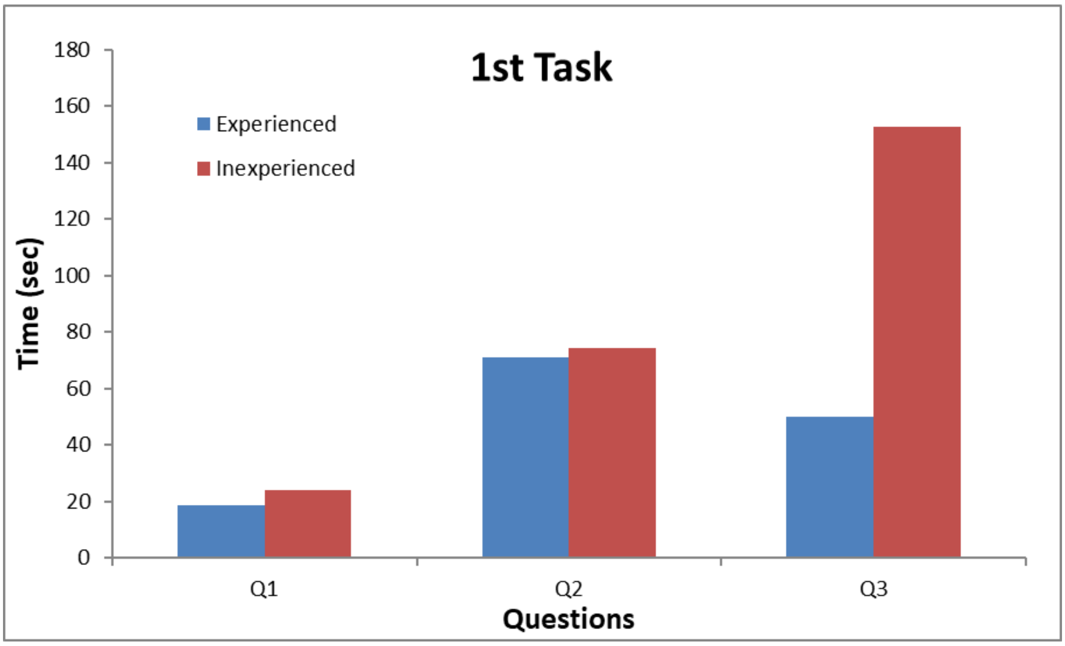


Figure 4.7: *Time spent by Experienced/ Inexperienced users on the Pendulum Lab simulation's task.*

4.3.4.2 Energy Skate Park simulation's questions

Figure 4.8 depicts the amount of time spent by experienced/ inexperienced users on each question of the "working with simulation" sub-phase, in the Energy Skate Park simulation's task.

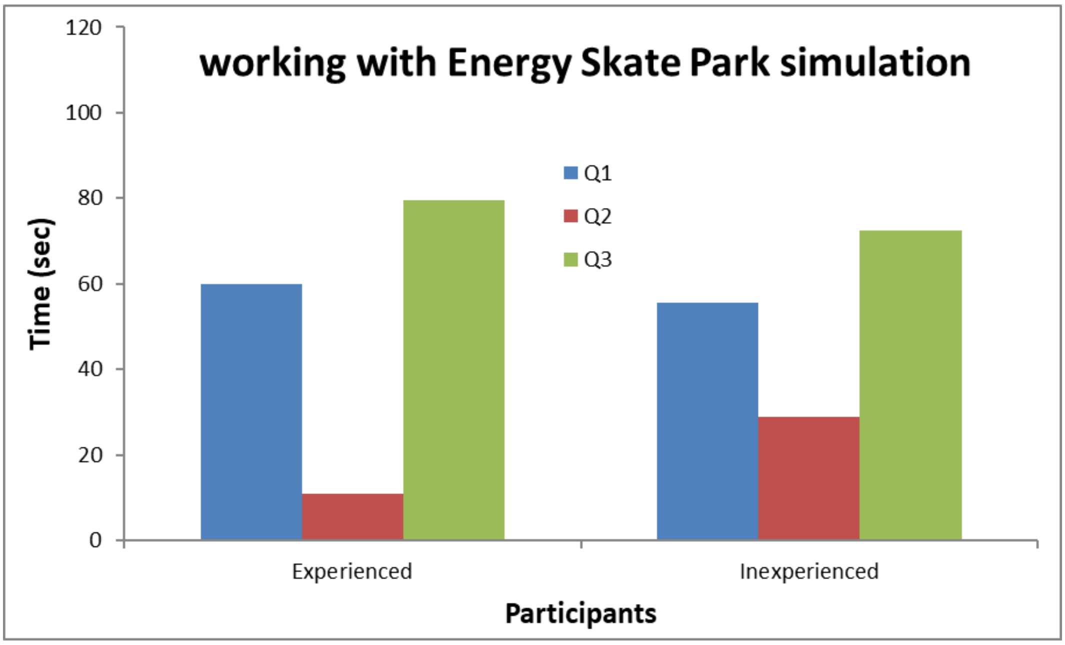


Figure 4.8: *Time spent on each worksheet's question of the Energy Skate Park simulation's task.*

In this case, both groups spent approximately one-third of their time on the first question (Experienced 40% /Inexperienced: 35%). Then they spend significantly less time on the second one (Experienced 7% /Inexperienced: 18%) and finally, they spent the rest of their time, about half of the whole phase's duration, on the third question (Experienced 53% / Inexperienced: 46%). Therefore, we notice a pattern on how the users spend their time on the eye-controlled task's three questions.

Figure 4.9 depicts the amount of time spent by experienced/ inexperienced users on each question of the "working with simulation" sub-phase, in the Energy Skate Park simulation's task.

Comparing the time spent on each question we observe that participants' behaviour is very similar between the two groups. On all three questions, both groups spend approximately the same amount of time (Q1: experienced: 60s/ inexperienced: 56s, Q2: experienced: 11s/ inexperienced: 29s, Q3: experienced: 80s/ inexperienced: 73s).

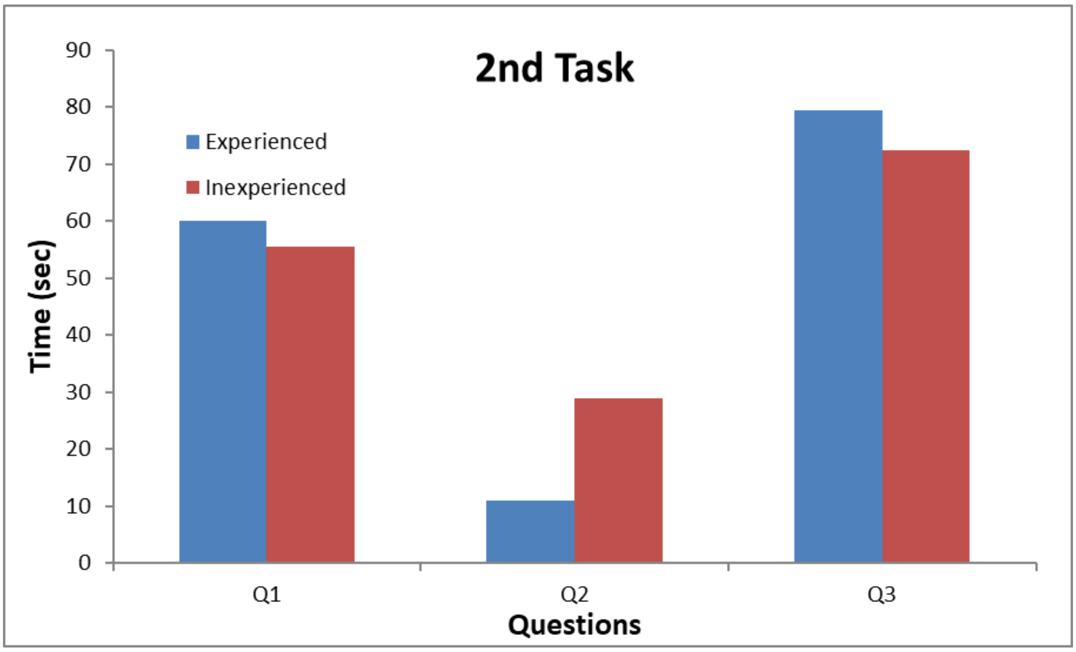


Figure 4.9: *Time spent on each worksheet's question of the Pendulum Lab simulation's task.*

In this case, both groups spent approximately one-third of their time on the first question (Experienced 40% /Inexperienced: 35%). Then they spend significantly less time on the second one (Experienced 7% /Inexperienced: 18%) and finally, they spent the rest of their time, about half of the whole phase's duration, on the third question (Experienced 53% / Inexperienced: 46%). Therefore, we notice a pattern on how the users spend their time on the eye-controlled task's three questions.

4.4 Conclusions

We summarize this chapter’s experiment findings and conclusions based on our initial research questions.

Our first research question was if users’ experience affects the time they need to familiarize with a simulation when it is first introduced to them. According to our results, both experienced and inexperienced users spend about the same amount of time to familiarize with a simulation, in both tasks. Therefore, it seems that their experience does not affect their time needs to get comfortable with it.

The second research question is about the time experienced/ inexperienced users spent working with the simulation, in order to answer three worksheet’s questions, concerning a Physics topic, and if that time depends on their expertise on the topic and their experience in problem-solving. The first task’s results suggest that their experience affects the time they need to use the simulation to complete the worksheet, as experienced users spent significantly less time to do so. On the other hand, in the second task, both experienced/ inexperienced users spend the same amount of time to answer the questions. Consequently, the users’ experience affects the time they need to work with a simulation and answer questions, but it is not the only determinant.

The third research question is a combination of the two previous questions, as it concerns the comparison between the time users spent familiarizing with the simulation and using it to answer the worksheet’s questions. Our results indicate that this depends on the simulation and worksheets nature rather than the users’ experience.

Finally, our last research question concerns the way experienced/ inexperienced users spend their time to use the simulation in order to complete the worksheet. In both tasks, we observe a similar behavior, between experienced and inexperienced users, in the way they spend their time to answer the worksheet’s questions. Although we observe the same tendency, in some cases the users’ experience plays an important role in the time the participants spend to answer a specific question.

Although, the previous results and conclusions are limited by the small number of our observations and should be verified by further research.

Chapter 5

Control methods comparison

5.1 Introduction

Humans interact with computers in many ways; the interface between humans and computers is crucial to facilitate this interaction. For example, when students' use computer simulations to conduct experiments and solve Physics problems, the tools used to interact with the simulation directly affect their performance. This can lead to them accepting or rejecting a certain way of interacting with the simulation, depending on its usability, difficulty, appealing, etc.

In this chapter, we compare two control methods, used by students with different level of expertise to work with computer simulations, in order to conduct experiments and answer questions regarding a Physics topic. The first method used to control the simulation was the 'traditional' one, that is moving the cursor on the computer screen with the mouse movement. The second control method is novel to the student and enables them to move the cursor with their pupil movement, with the use of an eye tracker.

We hypothesize that both types of users will need less time to familiarize with the simulation and work with it to conduct the appropriate experiments when using the traditional control method (mouse-control), as they are more used to it. Furthermore, because of their experience and confidence in using the mouse-controlled method, they would prefer it over the eye-controlled one.

The research questions that arise from our hypotheses and we seek to answer in this chapter are:

1. Using which control method do the users familiarize with the simulation faster?

2. Using which control method do the users complete the given tasks faster?

3. Which control method would the users prefer to use for a future experiment?

5.2 Experimental procedure

Time record: As described in previous chapters, in the experiment's second and third phase, all four of our study's participants have to complete two tasks. In each of these tasks, they must use a computer simulation in order to conduct experiments and answer the three corresponding worksheet's questions. The crucial part of the participants completing two tasks is that they control each one with a different method. In the first task (Pendulum Lab simulation) the cursor on the computer screen is controlled with the mouse movement (mouse-control), whine in the second task (Energy Sate Basics simulation) the screen cursor is controlled with the user's pupil movement (eye-control). It should be mentioned that the simulations used for the two tasks were very similar to each other and the worksheets were designed that way, so their context and difficulty is almost the same. Therefore, the two tasks were created almost identical, hoping that any spotted differences between the group's participants behavior during the experiment, will be caused by the different methods of interacting with the environment.

In order to compare the two control methods, we record and compare the time each participant spends on the 'familiarization' and 'working with simulation' sub-phases, between the two cases.

Interviews: In addition, after the participants are done with the two tasks, we ask for their feedback on the whole process. Since our sample is quite small, we do not hand any questionnaires to the participants to complete instead, we prefer to interview each one of them (experiment's phase 4). The interviewer is the same person that gave the oscillation lectures to the inexperienced users, explained the experiments' process and guided the participants through it. We wanted to make them feel as comfortable as possible in order to naturally express their thoughts on the tasks.

All the participants are asked the same questions. At first, they are asked to make some general comments on the whole experiment's process for example, if they found it interesting, difficult, boring, etc. Then we focus on the two task's simulations and worksheets. We wanted to know if they think found the content of any of the two more difficult than the other. Also, we ask if they preferred any of the simulations over the other. As the interview goes on, we focus on the two control methods. They are encouraged to express their thoughts on the two control methods used (mouse/ eye control), what kind of difficulties they faced and if they favor any of them. Finally, we let them see parts of the videos that the eye tracker created, showing their actions on the simulation and the worksheet and their fixation point of gaze. These parts were most likely parts that the user did something strange or unusual and were selected by the interviewer. We wanted the user to see his actions and explain them to us, for example, where does he start the experiment's process from and why. Finally, we transcribe all the participants' interviews (see Appendix) and try to justify the actions they made during the experiment and justify them according to their answers.

5.3 Results

5.3.1 Familiarization

We record the amount of time that both groups' participants spent on the 'familiarization' sub-phase of both tasks. Then we compare that time between the Pendulum Lab simulation's task (mouse-control) and the Energy Skate Park simulation's task (eye-control) for both groups.

Figure 5.1 depicts the time that participants spent on the 'familiarization' sub-phase for both cases (mouse/ eye control).

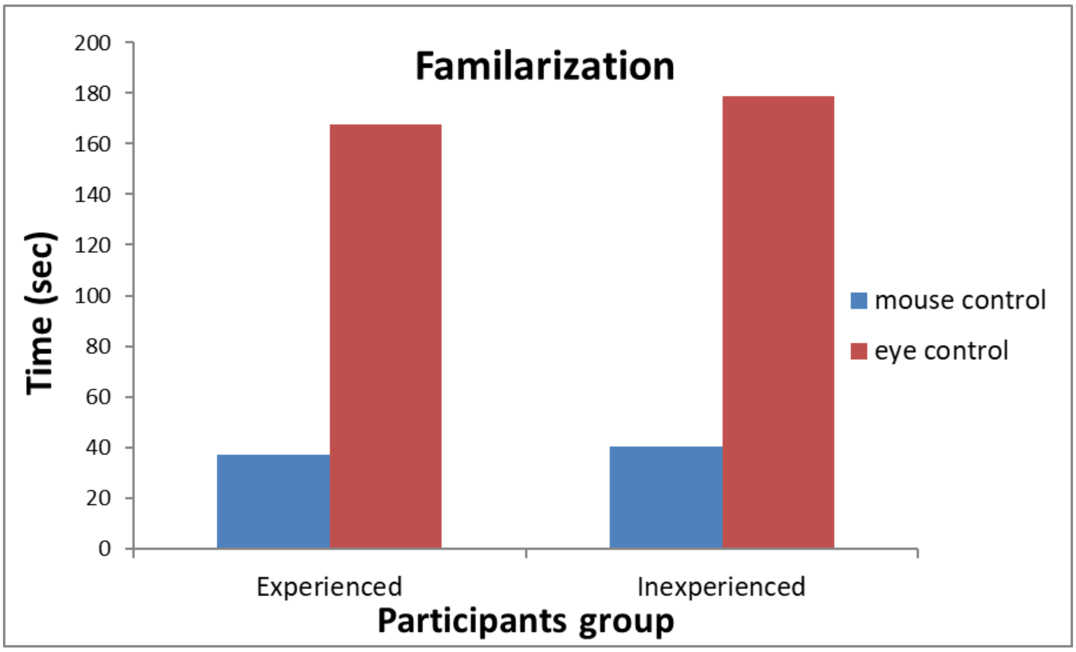


Figure 5.1: *Time spent on the familiarization sub-phase in the mouse/ eye control case.*

All users were familiar using the mouse's movement to control the cursor on the screen and as a result, they spent significantly less time in the mouse-controlled case's 'familiarization' sub-phase, compared to the whole task's duration (total average 39s, 17% of the whole task duration). Opposite to the mouse-controlled case, using the pupil movement to control the cursor (eye-control), is novel to the students, therefore the total time devoted to the familiarize with the simulation was drastically increased (total average 173s, 53% of the whole task duration).

It is clear that all users needed more time to familiarize with the simulation and set the object's initial conditions when using the eye-controlled method.

5.3.2 Working with simulation

We repeat the process followed in the previous sub-phase, for the ‘working with simulation’ sub-phase, as well.

Figure 5.2 depicts the time that participants spent on the ‘working with simulation’ sub-phase, for both cases.

However, in the ‘working with simulation’ sub-phase we do not observe the same results for both groups. Experienced users spend almost the same amount of time, using both control methods to answer the worksheet questions, with the time used for the eye-controlled task’s questions being slightly higher (mouse-control: 140s / eye control: 150s). On the other hand, inexperienced users needed significantly less time to answer the eye-controlled task’s questions, compared to the eye-controlled task ones (mouse-control: 251s / eye control: 157s). This result was surprising since the number and the difficulty of the questions in both cases are the same and the eye-control was novel to the users. Although, if we consider that the eye-controlled task was carried out right after the mouse-controlled and because the question’s and the simulation’s context was the same, we assume that cognitive processes took place during the first task, and the users used this new knowledge and the skills they acquired to complete the second task quicker. Therefore, we cannot reach any clear conclusions as to using which control method the users complete the worksheet’s questions faster.

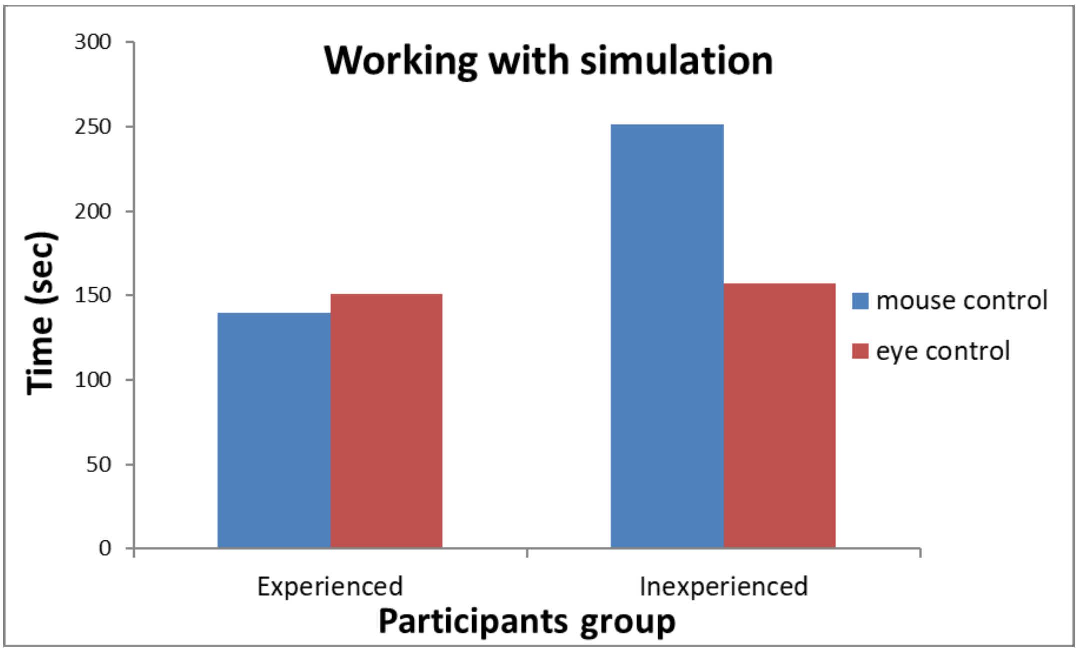


Figure 5.2: *Time spent on the ‘working with simulation’ sub-phase in the mouse/ eye control case.*

5.3.3 Worksheet's question analysis

In order to further examine the surprising result observed previously, that is inexperienced users spending less time to answer the worksheet's question using a novel control method (eye-control), rather than when using a control method they are more used to (mouse-control), we compare the time both groups spent on each question of the 'working with simulation' sub-phase.

5.3.3.1 Experienced users' question analysis

Figure 5.3 depicts the amount of time experienced users spent on each worksheet's question, for both control methods (mouse/ eye control)

Experienced users spend more time on the first question of the eye-controlled case compared to the mouse-controlled one (mouse-control: 19s, 13% of the whole sub-phase/ eye-control: 60s, 40% of the whole sub-phase. Even though the questions difficulty level is the same, this was expected since the users were still trying to get comfortable with the cursor's eye-control method.

On the second question, as they get more used to moving the cursor with their pupil movement, the time they spent on the eye-controlled task is significantly reduced (mouse-control: 71s, 51% of the whole sub-phase/ eye-control: 11s, 7% of the whole sub-phase. This difference may also be attributed to cognitive processes that may have taken place on the first task since the second question was identical on both task's worksheets.

On the third question, experienced users spent more time for the eye-controlled case compared to the mouse-controlled one (mouse-control: 50s, 36% of whole sub-phase/ eye-control: 80s, 53% of the whole sub-phase). This result most likely has to do with the actions that the user must do to find the right answer, rather than the control method itself. We study in detail the users' actions in the following chapter.

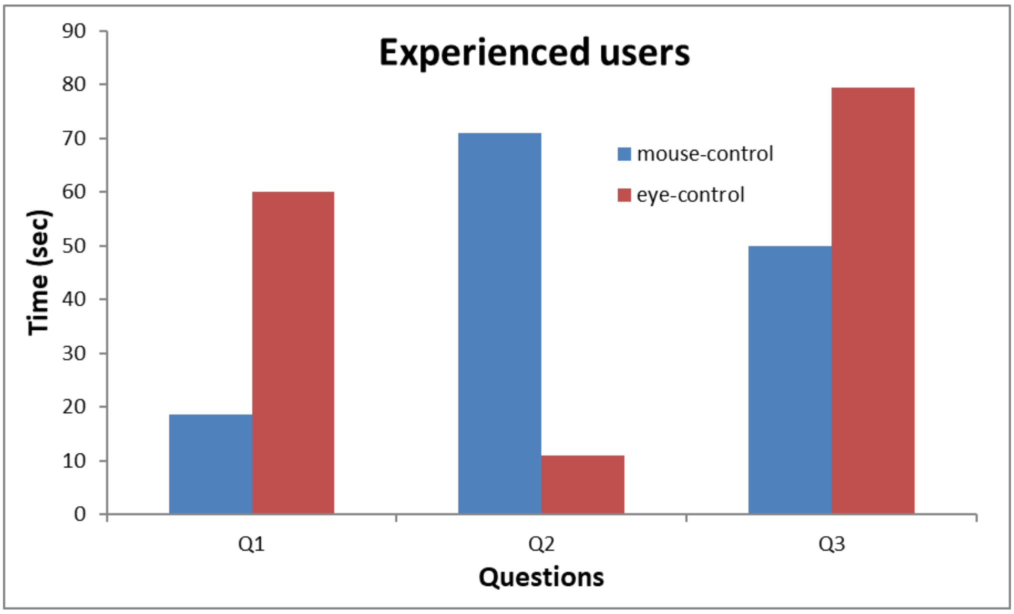


Figure 5.3: *Experienced user's time spent on the three worksheet's questions for mouse/ eye control cases.*

5.3.3.2 Inexperienced users' questions analysis

Figure 5.4 depicts the amount of time inexperienced users spent on each worksheet's question, for both control methods (mouse/ eye control).

On the first question, inexperienced users spent on the mouse-controlled case approximately half time than that they spent on the eye-controlled one (mouse-control: 24s, 10% of the whole sub-phase/ eye-control: 56s, 35% of the whole sub-phase). Just like with the experienced users, this result was expected, as they were still trying to get comfortable with the control method.

On the second question, the time inexperienced users spent on the eye-controlled case is significantly reduced (mouse-control: 75s, 30% of the whole sub-phase/ eye-control: 29s, 18% of the whole sub-phase).

On the third question, while the experienced users spend less time for the mouse-controlled case, for the inexperienced users we observe quite the opposite (mouse-control: 152s, 60% of the whole sub-phase/ eye-control: 72s, 46% of the whole sub-phase).

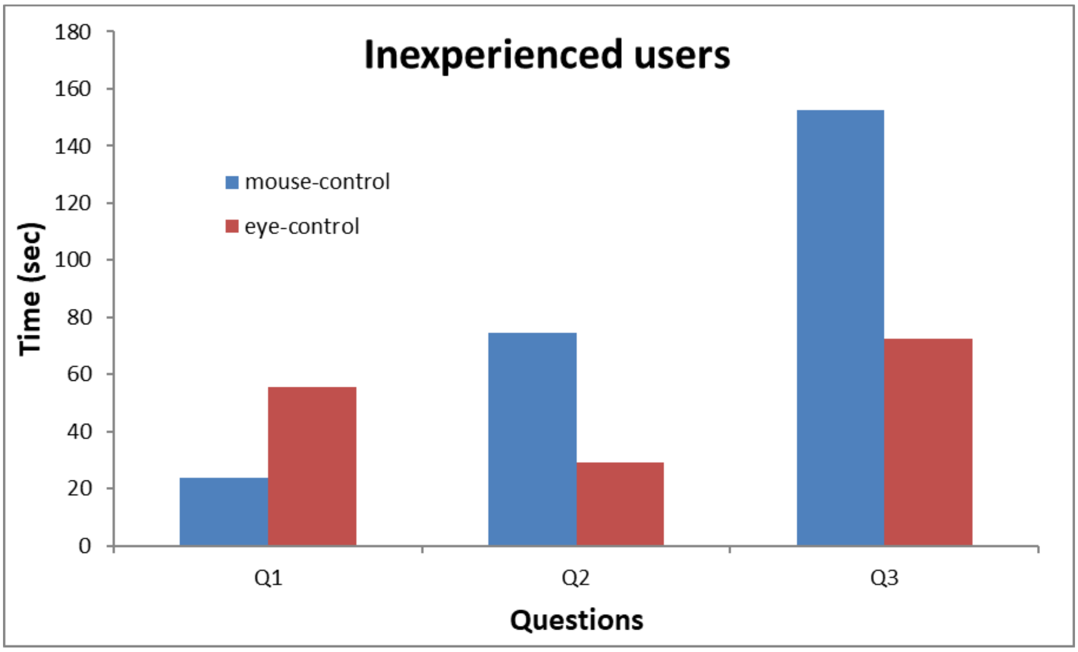


Figure 5.4: *Inexperienced user's time spent on the three worksheet's questions for mouse/ eye control cases*

Once again, the significant difference between experienced/ inexperienced users' behaviour comes down to the worksheets' third question. We conclude that the time that participants spend working with the simulation to answer the questions depends not only on the questions' context but on the way of interacting with the simulation. In order to deeper study and clarify this deviation on the participants' behavior, in the next chapter we pay attention to the users' visual behavior and their actions during each question.

5.3.4 Students' feedback

After each participant completes the two tasks, he/she gets interviewed. The questions asked in the interview focus on specific aspects of the experiments, for example, the simulations, the worksheets and the control methods. On most of them, we ask the participants to compare these aspects between the two cases.

One of our main concerns is which control method would the participants found more interesting and which one would prefer to use in the future. First, we have to make sure that both participants found the two tasks being on the same difficulty level so that their feelings will not be influenced by the task's content difficulty. All of them are asked the following question:

Q: For each task you were asked to answer a set of three questions. Did you find any of them more difficult to answer?

Inexperienced 1: No, they were both easy, you just had to be concentrated.

Inexperienced 2: No, the questions were almost the same in both tasks.

Experienced 1: No, I think the difficulty level was the same and overall easy. I don't think any of them was more difficult.

Experienced 2: No, I think they were the same.

We conclude that the participants indeed think that both tasks were on the same difficulty level. Therefore, any differences in the difficulty level between the two tasks should be due to their control method.

As the interview goes on, we ask the participants if they find any of the control methods more interesting to use. We expect that all of them would pick the eye-control as it was novel to them, compared to the traditional mouse-control method.

Q: Which control method did you find more interesting?

Inexperienced 1: The eye-controlled was better but it was more difficult, while I was gazing at the speedometer the cursor wouldn't go there!

Inexperienced 2: The eye-controlled, I liked it because it was challenging to try and move the skater with your eyes

Experienced 1: The eye-controlled for sure. Although you needed more time to complete the task.

Experienced 2: Definitely the one that I was using my eyes.

As expected, all the participants found the eye-controlled task more interesting than the mouse-controlled one, but we also see that all the users acknowledged it was more difficult to use.

Finally, we ask the participants which of the two control methods they would prefer to use on a future experiment.

Q: Which control method would you prefer to use in the future?

Inexperienced 1: If the eye-control had the same accuracy as the mouse-control, I would prefer it for sure. I believe this will happen in the future anyway.

Inexperienced 2: The eye control, I would definitely use it every day!

Experienced 1: The eye-controlled one. Although I would need much time to get used to it!

Experienced 2: I think the eye-controlled, it sounds like fun to use it for your everyday use, you just have to get used to it!

We conclude that despite the fact that all users found more difficult to interact with the simulation with the eye-controlled method, they would prefer to use it over the mouse-controlled one.

5.4 Conclusions

We summarize this chapter's experiment findings and conclusions based on our initial research questions.

Our first research question was about comparing the time our participants need to familiarize with a simulation, when it is first introduced to them, between using a novel control method (eye-control) and using the traditional one (mouse-control). As expected, we observe that using a novel control method to interact with the simulation is more time consuming than using the ordinary control method.

The second research question concerns the time users need to work with a computer simulation to answer questions regarding a Physics topic, by using two different methods of interacting with the computer. We conclude that that time does not depends solely on the control method itself, rather than on the combination of the actions that the user has to do and the control method's usability in making them.

Finally, the last research question has to do with the user's preference in the control methods used. We conclude that users would prefer to use an innovative and more exciting method of interacting with the computer, rather than the ordinary one, despite its' difficulties and limitations.

Chapter 6

Gaze patterns

6.1 Introduction

Our eyes are one of the primary tools we use for decision making and learning. It is also said that the eyes are the window to the soul, but they are also the gateway to knowledge about how people gather information and what influences their actions and decisions.

By using eye-tracking techniques we can study the movements of a participant's eyes during a range of activities. This gives insight into the cognitive processes underlying a wide variety of human behavior and can reveal things such as learning patterns and social interaction methods. In our case, we use eye tracking to study the visual behavior of students with different level of expertise, while working with computer simulations to conduct experiments and answer questions regarding a Physics topic. More specifically, we track experienced/ inexperienced users' visual activity during the experiment and compare it between the two groups. We also compare each group's actions with the process that should be followed to answer the questions, according to the tasks' designer. Our goal is to spot and study the differences between the two groups' visual behavior and its' deviations from the expected one. The research questions that arise and we seek to answer in this chapter are:

1. Where do experienced/ inexperienced users focus their gaze, when they are first introduced to the tasks' simulation and worksheet?

2. What are the main differences between experienced and inexperienced users' visual behavior?

3. What are the main differences between experienced/ inexperienced users' visual activity, compared to the expected one?

4. Can the users' visual activity deviation from the expected one lead them to wrong conclusions?

6.2 Experimental procedure

During the whole experiment, the eye tracker was tracking and collecting data of the users' visual activity, such as the x-y coordinates of the fixation point of gaze as a percentage of the screen dimensions, the fixations duration, the mouse cursor position, etc. Furthermore, the tracker records the computer screen so that a real-time video can be created, showing the users' actions during the whole process and overlays their fixation point of gaze on the image. On this video, we can later create specific areas that contain the necessary information for answering the questions. These areas are called Areas Of Interest (AOI). We can then collect special type of data for these areas such as how many times they were visited, for how long, the time spent on each area compared to that spend on the whole task, etc.

Areas of Interest

As the name suggests, these are areas on the computer screen that contain valuable information for the user in order to complete the whole process and are the areas that we are interested in. Based on the way we place the simulation and the worksheet on the screen in each task, we split the computer screen into two parts. Using the gaze point analysis tool, we create two main areas of interest, one dedicated to the worksheet and one to the simulation.

Main Areas of Interest:

1. Simulation (S): The left half of the screen where the experiment's simulation is placed.

2. Worksheet (W): The right half of the screen where the experiment's worksheet is placed.

The eye-tracker tracks the x-y coordinates of the user's fixation point of gaze as a percentage of the screen dimensions. The simulation is placed on the left half of the screen and the worksheet on the right. Therefore, when the x coordinate of the users' fixation point of gaze is lower than 50%, they are looking at the simulation and when it is over 50%, they are looking at the worksheet.

There are specific spaces in both the simulation's and the worksheet's Areas Of Interest that the participants should focus to extract the necessary information in order to answer the worksheet's questions. For each of the main Areas of Interest, we create sub-areas of interest, depending on their layout.

Simulation sub-Areas:

In the simulation's main Area Of Interest, we create three sub-Areas Of Interest as we can see in Figure 6.1.

i. Controls (C): This area includes the control panels where the users can select the represented quantities and manipulate the object's properties.

ii. Phenomenon (Ph): This is the area where the object's motion takes place.

iii. Representations (R): These areas include the spaces that represent the phenomenon's Physical quantities, for example, the energy bar graph (Energy), the period timer (Period), the speedometer (Speed), etc.

Worksheet sub-Areas:

In the worksheet's main Area Of Interest, we create three sub-Areas Of Interest as we see in Figure 6.2.

i. Instructions (In): The area where the experiment instructions are given.

ii. Prompts (P): These areas include the three questions of each worksheet (Prompt 1,2,3).

iii. Answers (A): These areas include the answers for the three questions on each worksheet (Answer 1,2,3).

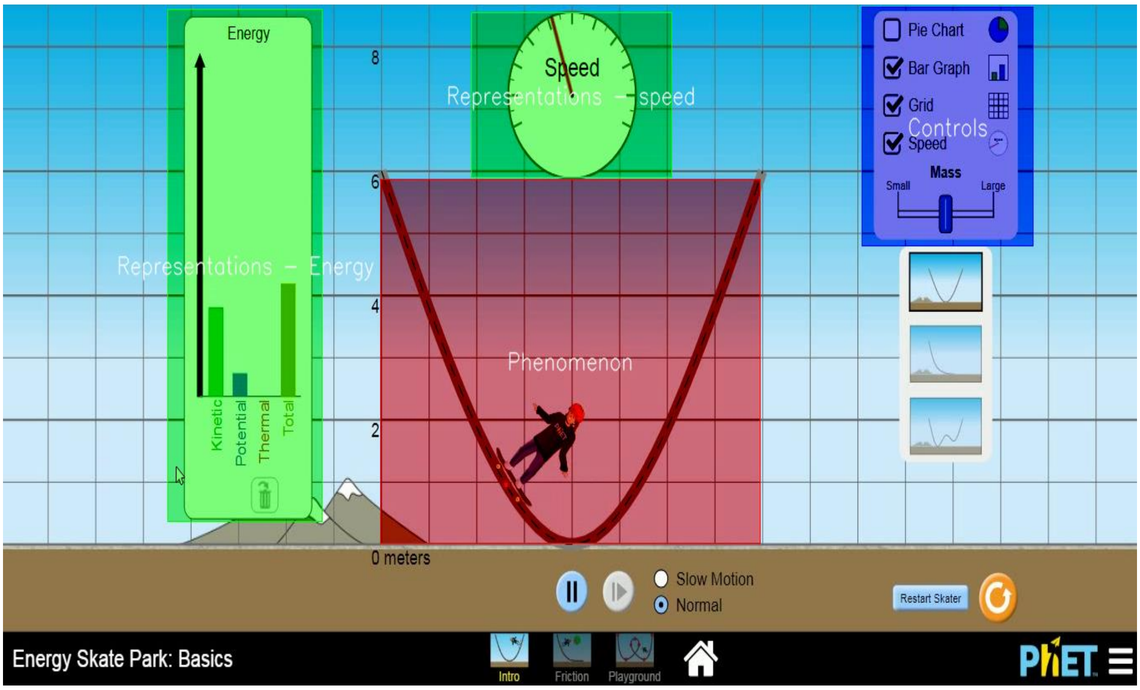
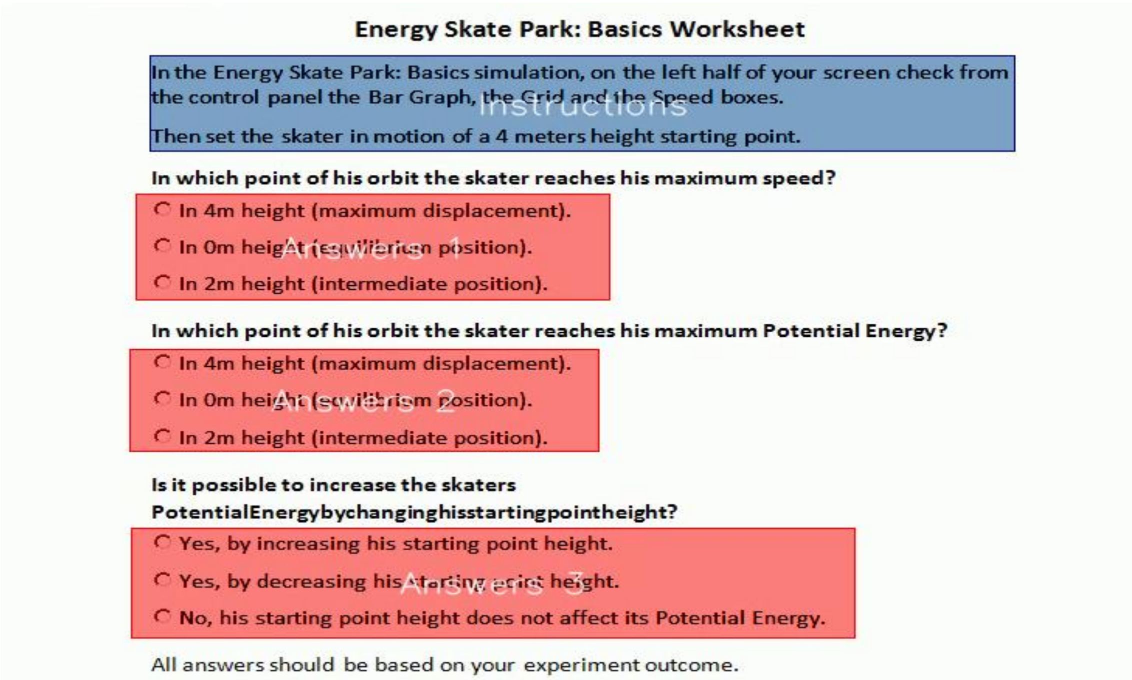


Figure 6.1: *'Energy Skate Park: Basics' simulation's sub-Areas of Interest.*



Energy Skate Park: Basics Worksheet

In the Energy Skate Park: Basics simulation, on the left half of your screen check from the control panel the Bar Graph, the Grid and the Speed boxes.

Then set the skater in motion of a 4 meters height starting point.

In which point of his orbit the skater reaches his maximum speed?

- In 4m height (maximum displacement).
- In 0m height (equilibrium position).
- In 2m height (intermediate position).

In which point of his orbit the skater reaches his maximum Potential Energy?

- In 4m height (maximum displacement).
- In 0m height (equilibrium position).
- In 2m height (intermediate position).

Is it possible to increase the skaters PotentialEnergybychanginghisstartingpointheight?

- Yes, by increasing his starting point height.
- Yes, by decreasing his starting point height.
- No, his starting point height does not affect its Potential Energy.

All answers should be based on your experiment outcome.

Figure 6.2: *'Energy Skate Park: Basics' worksheet's sub-Areas of Interest.*

For both the ‘familiarization’ and the ‘working with simulation’ sub-phases, we graph the user’s fixation point of gaze in the Areas of Interest mentioned above, with respect to time. We also present the expected behavior and the anticipated gaze transitions for both groups in the ‘familiarization’ sub-phase and for each question of the ‘working with simulation’ sub-phase. Finally, we compare both groups’ visual behavior between them but also with the expected one. Our goal is to spot the differences between the users’ visual behavior e.g. where do participants with different level of expertise first focus their gaze, their gaze transitions between the different areas of interest, etc.

6.3 Results

6.3.1 Familiarization's sub-phase gaze transitions.

At the beginning of the experiment's second and the third phase, we introduce to each participant the task's simulation and its corresponding worksheet, at the same time, without prompting them where to start their experimental process form.

It was anticipated that the gaze transition sequence between the areas of interest would be different for experienced and inexperienced users. We expected that inexperienced users would be more attracted to the simulations since they are not using them very often. Therefore, when they are introduced to the simulation and the worksheet, they would first focus on the simulation and spend a lot of time on it trying to frame the conceptual domain and run it, in an attempt to explore its affordances and functionality. Similar findings were reported by Michaloudis et al, who tracing students' clicks, have found that when students are facing a simulation, they try to explore it in order to understand it, before focusing on the problem itself. Only after they feel comfortable with the simulation, they would turn their attention to the worksheet to read the experiments' instructions.

On the other hand, we expected that experienced users would not spend time to explore the simulation but would rather start the process with reading the worksheet's instructions and follow them strictly to conduct the experiment and answer the questions.

To study the participant's behaviour when they are first introduced to the simulation and the worksheet, we graph their fixation point of gaze in the two corresponding Areas of interest, with respect to time for the 'familiarization' sub-phase of the first task. Our objective is to see the participants' first reactions when they are introduced to the environment, for example, where do they first focus their gaze on, how they choose to interact with the simulation, etc.

Figure 6.3 depicts all four users' fixation point of gaze between the simulation and worksheet areas of interest for the first task's 'familiarization' sub-phase.

It is clear that both types of participants choose to start the process by focusing on the worksheet's area, instead of the simulation's. It was only after spending some time reading the instructions when they turn their attention to the simulation. During the rest of the 'familiarization' phase, they regress their gaze between the two areas. Being guided by the worksheet's instructions, they set the initial conditions for the object's motion and select the appropriate Physical quantities to be represented.

We conclude that both groups' participants do not only spent approximately the same amount of time to familiarize with the simulation (Fig. 4.2) but they also do it in similar ways; first reading the worksheet's instructions and by following them making the necessary actions on the simulation without exploring it any further.

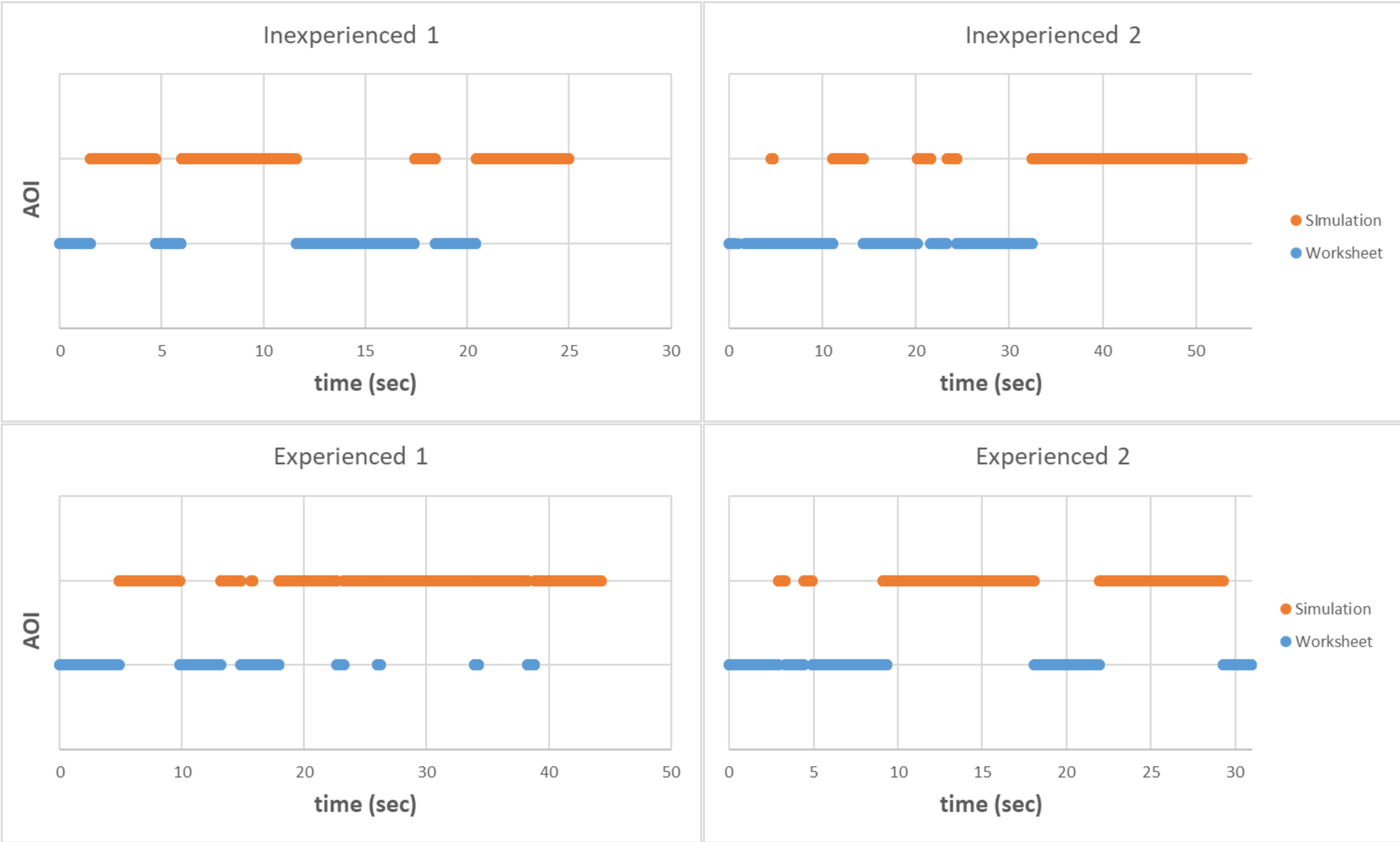


Figure 6.3: *Participant's fixation point of gaze between the simulation's and worksheet's AOI for the mouse-controlled 'familiarization' sub-phase*

The fact that all users preferred to first focus on the worksheet's instructions and not on the simulation caught our attention immediately, as it was really surprising. We wanted the users to give us an explanation for their behavior so during the interview, we let them see on the video the tracker creates the parts where the tasks' simulation and worksheet were presented to them. On the video, they could also see their point of gaze on the screen. We quote the corresponding parts from the interviews.

Inexperienced 2

Int.: Here is when we present to you the simulation and the corresponding worksheet and we ask you to begin the process. As we can see you go straight to the worksheet! Why? Don't you find the simulation exciting?

Inexp. 2: No, I just wanted to first check the questions and then focus on the simulation.

Experienced 1

Int.: In the beginning, when we present to you the simulation and the worksheet we can see that you immediately start reading the worksheet's instructions without paying attention to the simulation. Why? Didn't the simulation exciting?

Exp. 1: Indeed! I first read what I have to do and then I looked at the simulation! I don't know, I did it unconsciously!

Experienced 2

Int.: Here we can see what was on your screen and where exactly you were looking. At the beginning we see that you start reading the worksheet; Didn't the simulation caught your attention?

Exp. 2: That's right! Maybe because I have already work with the simulation before!

From the user's feedback we conclude that all of them confirm that they decide to start their experiment process by first reading the instructions and follow them strictly, without further exploring the simulations affordances. Similar findings were reported by Tsai et al. who examined how students inspect complex graphics used in problem solving with the context of earth science. Their results show that in solving an image based multiple-choice science problem, students, in general, paid more attention to chosen options than rejected alternatives and spent more time inspecting relevant factors than irrelevant ones.

6.3.2 Worksheets' questions gaze transitions.

After the users set the object (Pendulum/ Skater) in motion, the 'familiarization' sub-phase ends and the 'working with simulation' sub-phase begins. In this sub-phase, the participants have to find the answer to the three worksheet's question. To do so, they must interact with the simulation. Although, only a few areas on the simulations (AOI) contain useful information to the users and in order to find them they should follow a specific process for each question. (e.g. make the necessary preparations to the simulation, observe the appropriate quantities, etc).

For both cases (mouse-controlled / eye-controlled) we present the expected process that the users should follow to find the correct answers, according to the task's designer.

6.3.2.1 1st question (Q1)

Mouse-controlled case: In this case's (Pendulum Lab simulation) first question the participants are asked to measure the pendulum's period. After they select the initial conditions and set the pendulum in motion in the familiarization sub-phase, they must use the Period Timer to measure its period and finally choose the correct answer from the three options. Therefore, the gaze transition sequence between the areas of interest are expected to be as follows:

First, they read the question on the corresponding worksheet's area (**Prompt -P**), then turn their attention to the pendulum's motion (**Phenomenon -Ph**) and by using the Period Timer (**Representation -R**) measure the pendulum's motion period. Finally, they have to focus on the three worksheet's answers (**Answer –A**) in order to choose the correct one.

Eye-controlled case: In this case, in order to find the correct answer, the users must follow a similar process like the one described previously. The users are asked to find in which point of the skater's orbit his speed reaches its maximum value. After the users set the skater in motion from the proper height in the familiarization sub-phase, they must use the speedometer to observe his speed and find out in which point of his motion it reaches its maximum value. The gaze transitions should be almost identical to the previous case:

First, the users have to read the question on the worksheet (**Prompt -P**) and then by regressing their gaze between the skater's motion (**Phenomenon -P**) and the speedometer (**Representations -R**), they decide where his speed reaches its maximum value. Finally, they have to focus on the three answers (**Answer –A**) in order to choose the correct one.

We call the first question's gaze transitions' sequence the 'P-Ph-R-…-Ph-R-A' model.

Figure 6.4 & 6.5 depict the users' fixation point of gaze on the areas of interest with respect to time for the first question of the mouse-controlled and the eye-controlled cases, respectively.

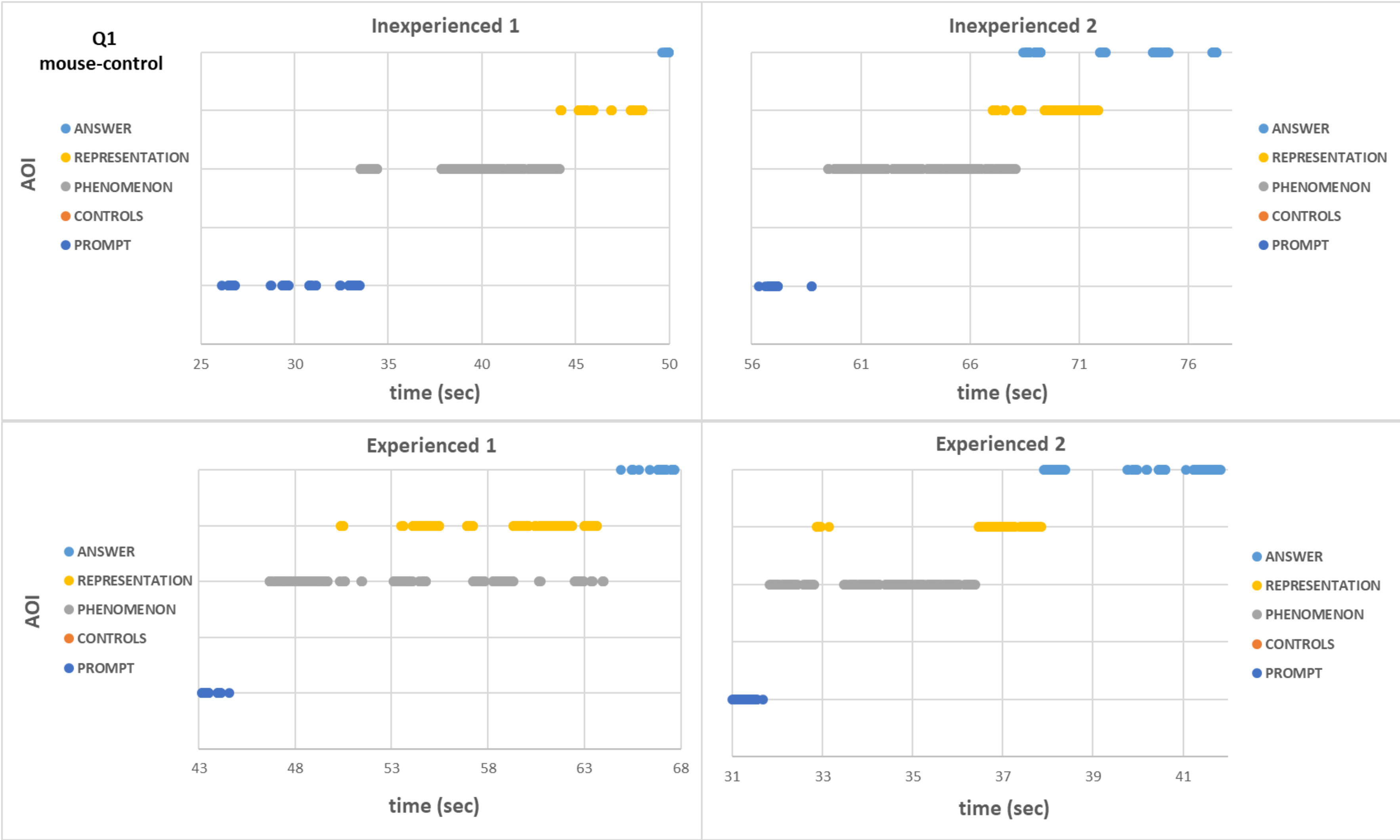


Figure 6.4: *Participants AOI fixation point of gaze on the first question of the Mouse-Controlled case.*

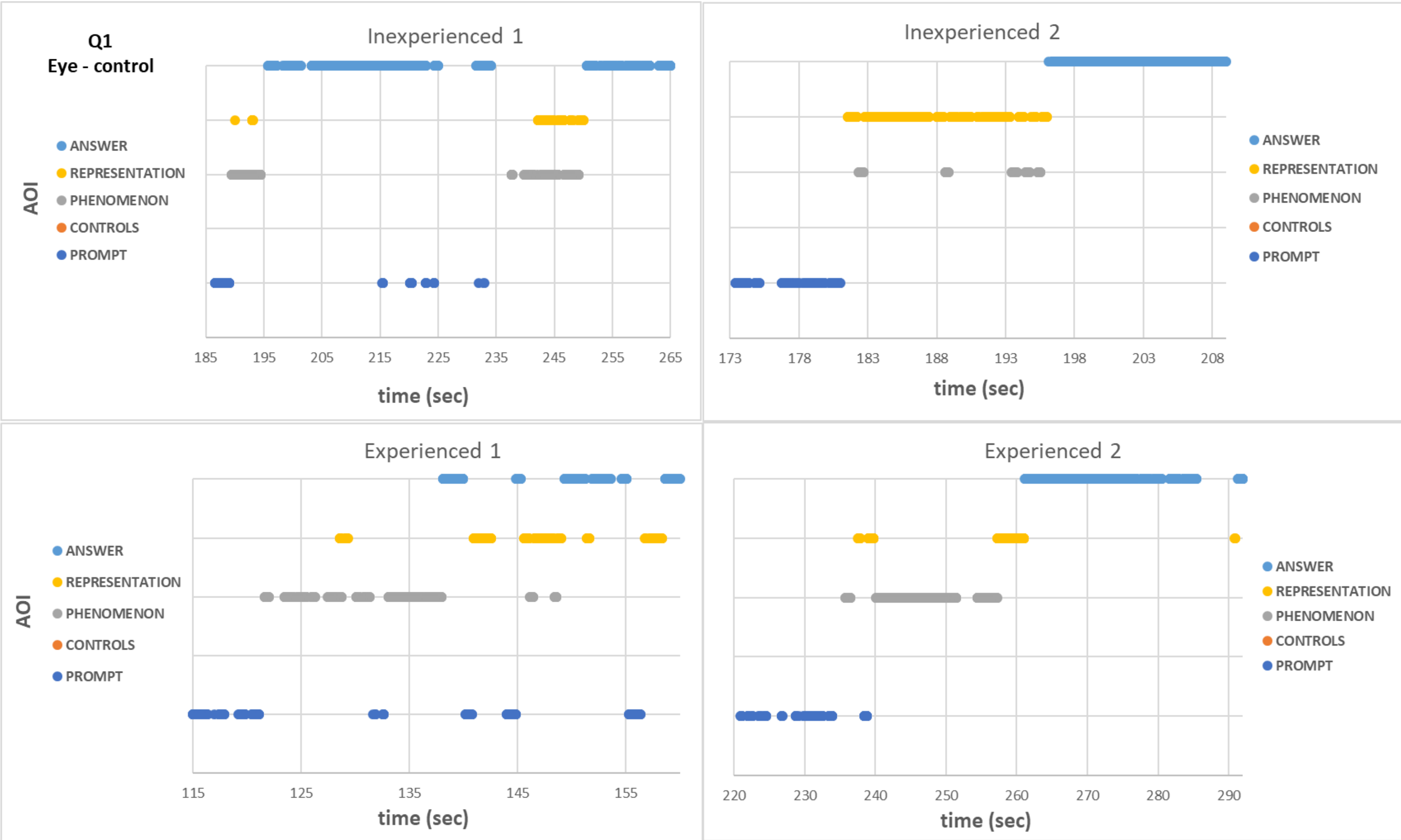


Figure 6.5: *Participants AOI fixation point of gaze on the first question of the Eye-Controlled case.*

Mouse-controlled case: In this case, both types of users' visual behavior is quite similar to the expected. All users start the process by spending some time reading the question (Prompt AOI - blue area) and then focus on the pendulum's motion (Phenomenon AOI – grey area). Afterward, they turn their attention to the Period Timer to measure the pendulum's motion period (Representation AOI – yellow area) and finally to the answers area to choose the correct one (Answers AOI – light blue area).

The only difference between the two types of users is that the experienced users tend to regress their gaze between the Phenomenon and the Representation areas of interest, while the inexperienced first focus on the phenomenon and then on the representations, without regressing their gaze back and forth.

Eye-controlled case: In this case, the gaze transition that the users make between the areas of interest are similar to the previous case. Inexperienced user's 2 and Experienced user's 2 visual behavior is identical to the previous case; they first spend some time reading the question (Prompt), then they focus on the skater's motion (Phenomenon) and the speedometer (Representation) and regress their gaze between these two areas until they find the correct answer and finally pick it from the three options given (Answer). Although Inexperienced user 1 and Experienced user 1 visual behavior is similar to the previous case, it is not identical. Inexperienced user 1 start the process by reading the question (Prompt). Then he checks the Phenomenon and the Representation areas for the first time, but instead of spending time to find an answer on his own, he checks the possible answers given. He then gets back to the skater's motion and represented speed in order to find out which one of the three options is the correct one and select it on the worksheet answer's area. Experienced user 1 follows the same process; she begins by reading the question and then while she observes the skater's motion and speed, she keeps checking the three possible answers to pick the correct one.

In this case, we do not observe differences in the visual behavior between the two groups but between the groups' participants instead.

6.3.2.2 2nd question (Q2)

Mouse-controlled case: In this case's second question, the participants are asked to find in which point of the pendulum's orbit it's Potential Energy reaches its minimum value. In the 'familiarization' sub-phase the users were advised to open the Energy graph so that the pendulum's Potential and Kinetic Energy would be displayed on the screen. All they have to do in order to answer this question is regress their gaze between the pendulum's motion and the energy graph to find out in which point of the orbit, the Potential Energy reaches its minimum value. Finally, they have to choose the right answer from the three options. Therefore, the gaze transition sequence between the areas of interest is expected to be as follows:

First, they read the question on the corresponding worksheet's area (**Prompt - P**), then turn their attention to the pendulum's motion (**Phenomenon -Ph**) and the Energy Graph (**Representation -R**). By regressing their gaze between these two areas they find out where the pendulum's Potential Energy reaches its maximum value. Finally, they have to choose the right answer from the three options (**Answer –A**).

Eye-controlled case: The second question on the eye-controlled case is almost identical to that on the mouse-controlled one. The only difference is that we ask the point of the skater's orbit where the Potential Energy reaches its maximum value. The process that the users have to follow to answer this is identical to that described on the mouse control case. Therefore, the gaze transitions are expected to be the same.

We call this question's gaze transitions' sequence the 'P-Ph-R-...-Ph-R-A' model.

Figure 6.6 & 6.7 depict the users' fixation point of gaze on the areas of interest with respect to time for the second question of the mouse-controlled and the eye-controlled cases, respectively.

In the mouse-controlled case, we see that the experienced users follow the expected process to find the answer. They begin by reading the question (Prompt), then they turn their attention to the object's motion (Phenomenon) and the Energy Graph (Representation) and regress their gaze between these two areas until they find the correct answer, and finally select it from the given options (Answers). Also, the inexperienced users follow a similar process to that experienced users did.

The main difference between the two groups visual behavior is that inexperienced users tend to read the possible answers before finding one on their own or while searching for one. On the other hand, experienced users first find their own answer and then select it from the three options given.

In the eye-controlled case, inexperienced users follow the expected process to find the answer. They begin by reading the question (Prompt), then they turn their attention to the skater's motion (Phenomenon) and the Energy Graph (Representation) and regress their gaze between these two areas until they find the correct answer, and finally select it from the given options (Answers). In this case, they do not seem to need to check the possible answers in advance. Furthermore, they spend very little time on the phenomenon and the representation areas, compared to the previous case. Experienced users, on the other hand, follow a different process. After reading the question they never focus on the object's motion and one of them does not even look at the simulation at all and just answer the question immediately.

The main difference between the two groups is that experienced users seem to feel confident enough to answer the question without using the simulation, while inexperienced users follow the expected procedure of regressing their gaze between the areas of interest to find the right answer.

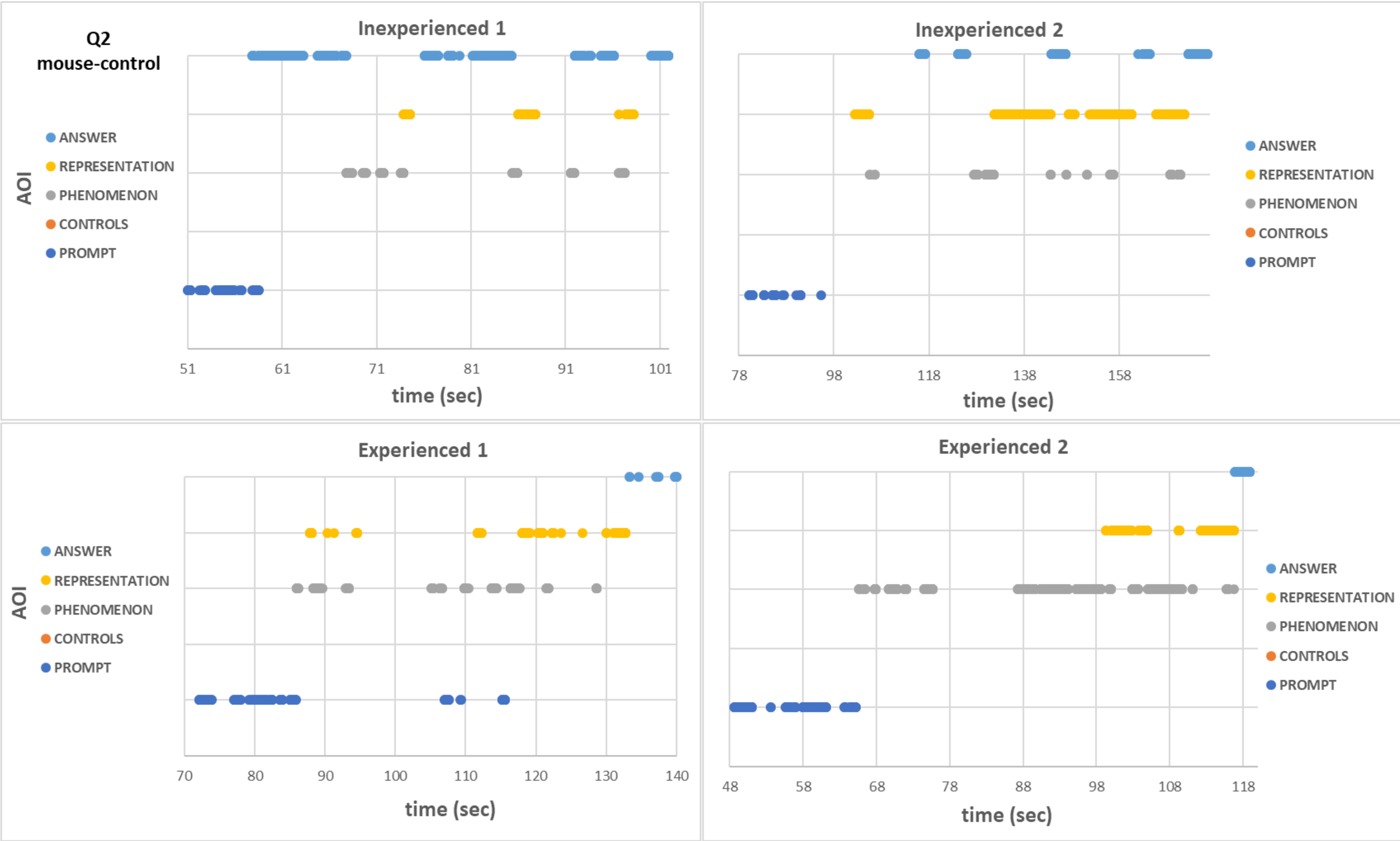


Figure 6.6: *Participants AOI fixation point of gaze on the second question of the Mouse-Controlled case.*

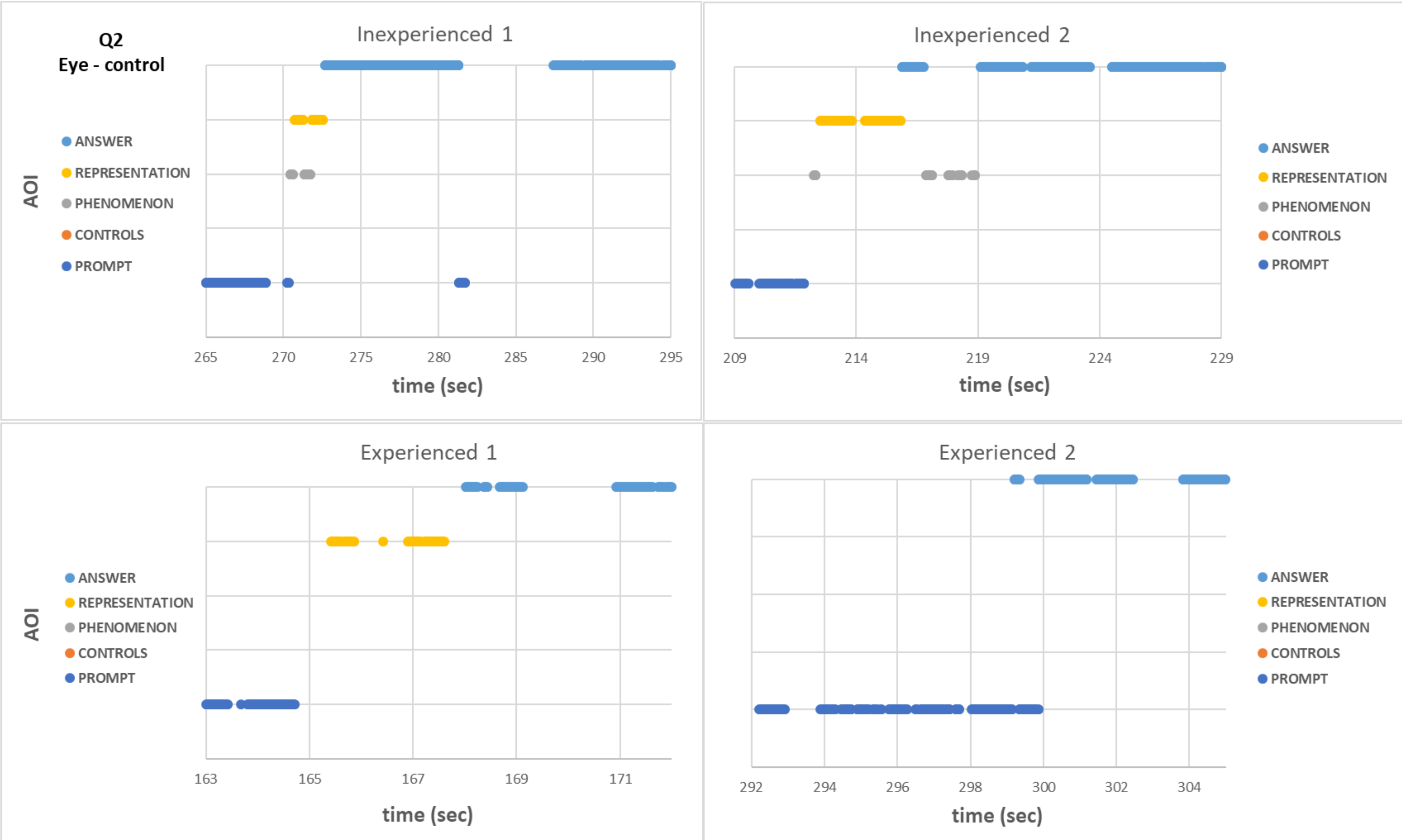


Figure 6.7: *Participants AOI fixation point of gaze on the second question of the Eye-Controlled case.*

6.3.2.3 3rd question (Q3)

Mouse-controlled case: In this case's last question, the participants are asked to find out If it is possible to increase the pendulum's Potential Energy by changing its mass. In order to answer the question, the participants must change the object's mass from the control panels and then observe the object's motion and its represented energy on the Energy Graph. They may repeat the process as many times as they want to make sure what is the outcome on the pendulum's energy when they increase or decrease its mass. After they figure that out, they have to pick the right answer on the worksheet's answer area. The gaze transition sequence between the areas of interest is expected to be as follows:

First, the users read the question on the corresponding worksheet's area (**Prompt -P**). Afterward, they should focus on the control panels (**Controls -C**) to change the object's mass and then turn their attention to the pendulum's motion (**Phenomenon -Ph**) and the Energy Graph (**Representation -R**). In order to see how their change affects them, they may repeat this process many times. Finally, they have to pick the right answer in the corresponding worksheet area (**Answer –A**).

Eye-controlled case: In this case, the last question is once again similar to the previous case. Here the participants are asked to find out if it is possible to change the skater's Potential Energy by changing his starting point's height. In order to answer this question, the users have to set the skater in motion from various heights and observe the outcome on its' potential energy. Finally, they have to pick the right answer on the worksheet. Although the two case's questions and the process to find the answers are quite similar, the gaze transitions between the areas of interest should differ. In order to change the skater's starting height, the users have to stop his motion and set him on a different point on the ramp, while in the previous case they could just use the mass slider from the control panels to change the pendulum's mass. Therefore, in this case, the users do not have to focus on the control panels. The gaze transition sequence between the areas of interest is expected to be as follows:

First, the users read the question on the corresponding worksheet's area (**Prompt -P**). Afterward, they should stop the skater's motion and set him on a different starting point (**Phenomenon -Ph**) and observe the outcome on the Energy Graph (**Representation -R**), in order to see how their change affects his energy, they may repeat this process many times. Finally, they have to pick the right answer in the corresponding worksheet area (**Answer –A**).

The beforementioned gaze transition sequence between the worksheets and simulation areas of interest is called the "P-Ph-R-…..-Ph-R-A" model.

Figure 6.8 & 6.9 depict the users' gaze transitions between the areas of interest for the third question of the mouse-controlled and the eye-controlled cases, respectively.

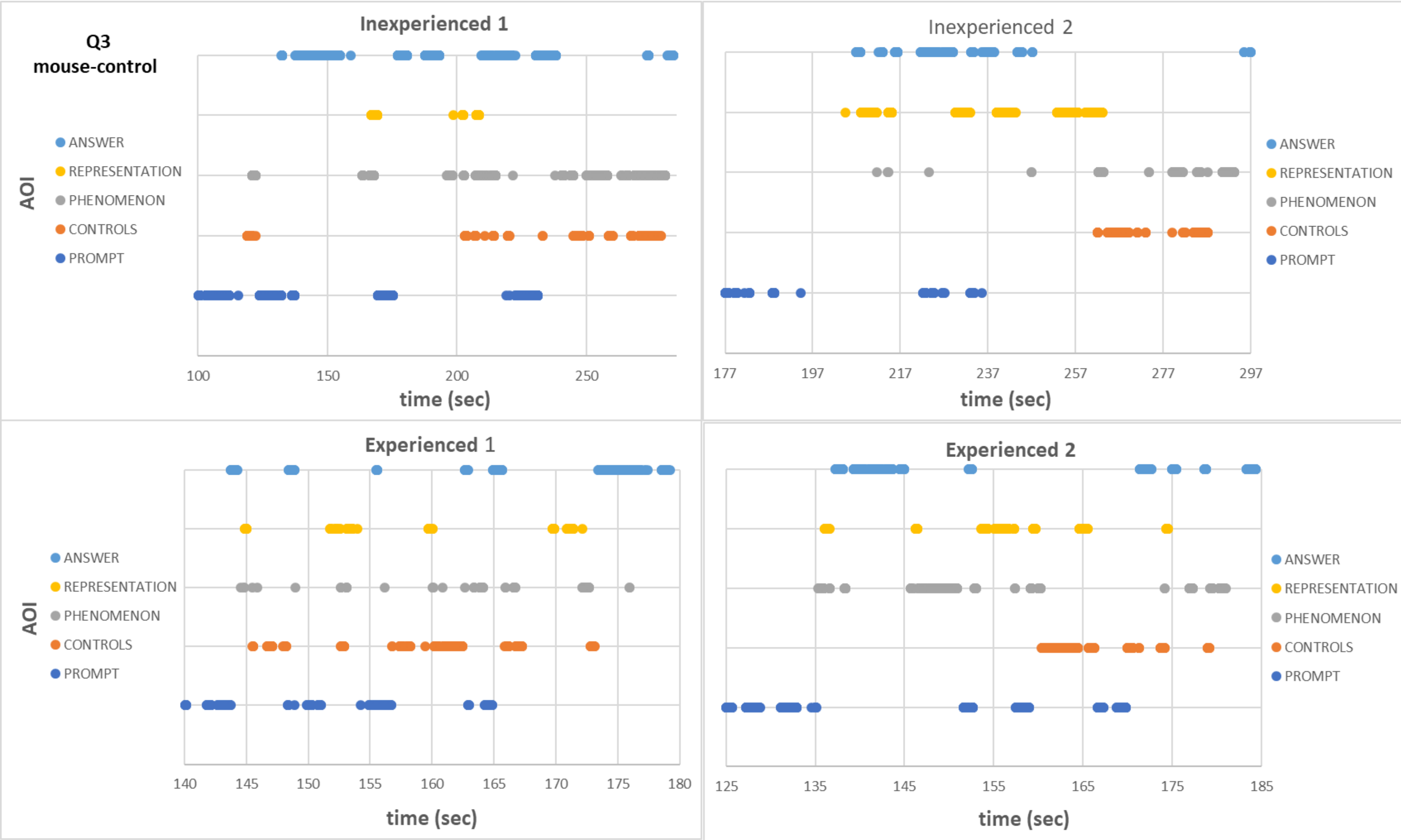


Figure 6.8: Participants AOI fixation point of gaze on the third question of the Mouse-Controlled case.

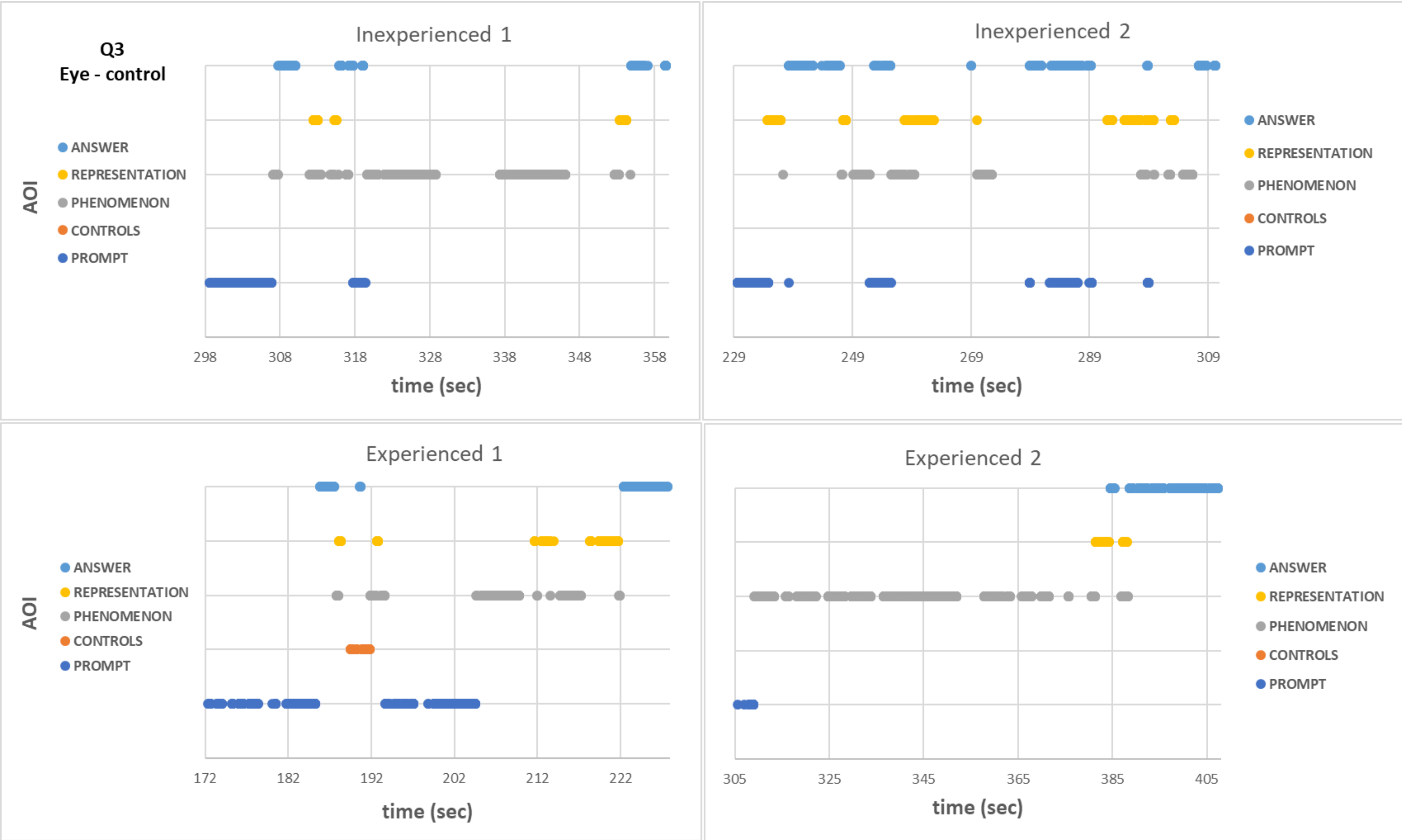


Figure 6.9: Participants AOI fixation point of gaze on the third question of the Eye-Controlled case.

Mouse-controlled case: In this case experienced users' visual behavior is very close to the expected. First, they read the question on the worksheet area. Then they search on the simulation how they can manipulate the object's mass. After they find that out, they keep changing its' value and regress their gaze between the phenomenon and the Energy Graph to find how do their changes affect the pendulum's motion and its energy. The only difference between the expected standard process is that during the whole process they keep regressing their gaze to the question's and answer's area. On the other hand, we see that inexperienced user's skip a very important step in the expected process. They start by reading the question and then try to find how to manipulate the pendulum's mass too. Although when they find that out and start making changes to its value, they just check the object's motion and never gaze back to the Energy Graphs, to see if their changes had any effect on the energy. This can lead them into picking a wrong answer, based on the fact that the pendulum's motion is not affected by its mass.

The main difference between the two types of users is that experienced participants tend to fixate directly on the resulting output right after they change the inputs from the control panels, while the inexperienced ones seem to gaze to the phenomenon represented in the simulation, trying to realize the effect that change had.

Eye-controlled case: In this case's last question, we see that the process that both types of users follow to find the correct answer, is quite similar to the expected. Experienced users start the process by reading the question. Then they mainly focus on the phenomenon area to change the skater's starting point height, before observing the resulting outcome on the energy graph. Finally, they turn their attention to the worksheet to pick the correct answer. Inexperienced users also follow the same process with the difference that they check the possible answers before finding one on their own.

6.3.3 Worksheet answers success' rate.

Following the exposure of the differences between the users' visual behavior and the deviations from the expected one, we seek to find if these deviations could lead the users into the wrong conclusions. After all participants are done with the experiment, we gather the two worksheets each one completed and check their answers

Figure 6.10 & 6.11 depicts the experienced/ inexperienced users success' rate on each worksheet's question for the mouse-controlled and the eye-controlled cases respectively.

In the mouse-controlled case's first and second question we did not observe any significant deviations in both groups' users' visual behavior, from the expected one. As a result, both users of the experienced and inexperienced group answer these questions correctly. Although in the last worksheet's question we spotted the most significant difference between the experienced/

inexperienced users' behavior. In the inexperienced user's actions, we spotted a crucial deviation from the expected process, that is never checking the resulting outcome of changing the Pendulum's mass on its' Energy. As we can see this lead both inexperienced users into choosing the wrong answer. On the other hand, experienced users follow the expected process, and both answer the question correctly. Similar findings were recorded by Susac et al who applied eye-tracking to mathematics education. The found a correlation between the number of fixations and a student's efficiency in equation solving, suggesting that better performing students were better at focusing on important components.

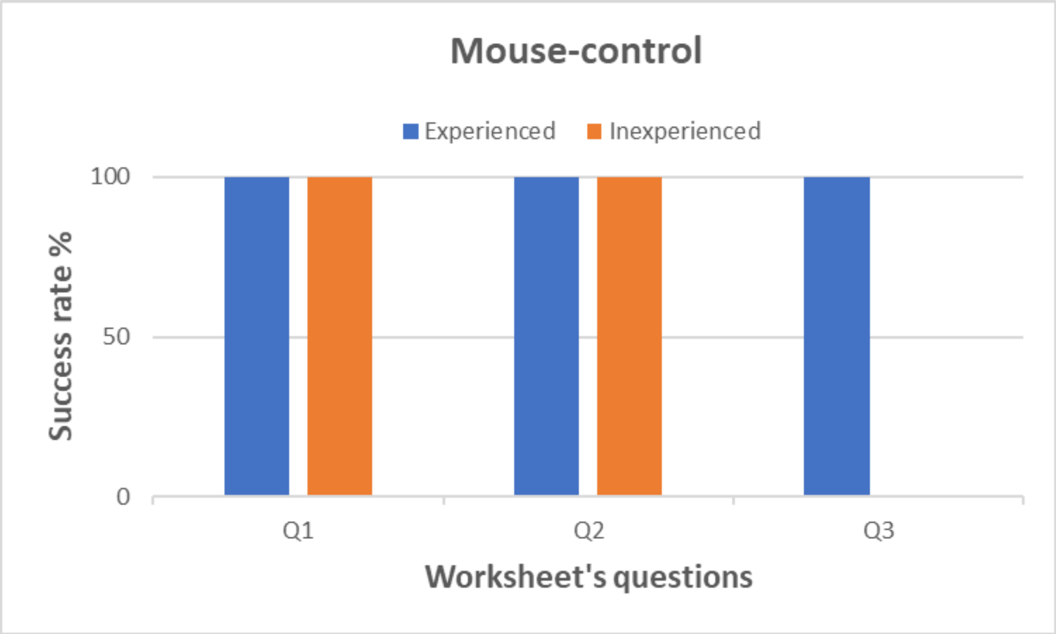


Figure 6.10: Success' rate of the experienced/ inexperienced users for the mouse-controlled case.

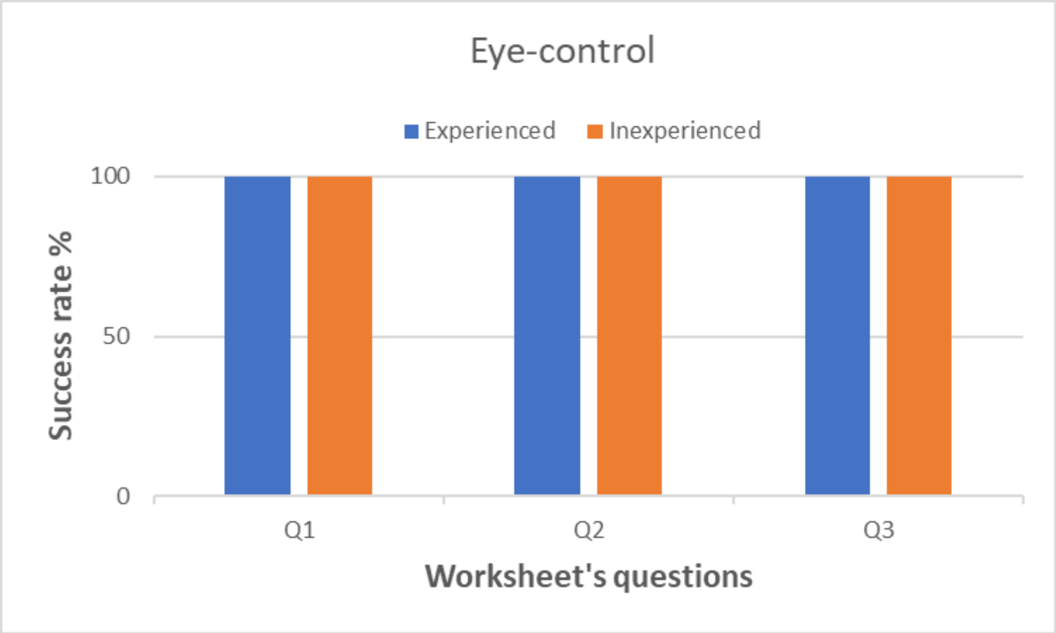


Figure 6.11: Success' rate of the experienced/ inexperienced users for the eye-controlled case.

On the other hand, in the eye-controlled case, both groups' participants actions were quite similar to the expected and were no significant deviations. Therefore, as we can see on the success' rate graph all of them answer all three questions correctly.

6.4 Conclusions

In this chapter, we aimed to study the users' visual behavior using eye tracking techniques. We summarize this chapter's experiment findings and conclusions based on our initial research questions.

Our first concern was to find out where do participants focus their gaze when they are first introduced to a task's simulation and worksheet. Our findings suggest that both experienced and inexperienced users decide, either consciously or subconsciously, to start the process by reading the worksheet's instructions and follow them strictly, without further exploring the simulations affordances.

Secondly, we aim to uncover the differences between experienced/ inexperienced users' visual behavior while implementing the two tasks. Our general findings are:

- Experienced users tend to regress their gaze between the phenomenon and the represented Physical quantities more often than the inexperienced ones.

- Inexperienced users tend to read the possible answers to a question and try to prove one of them right, while experienced users find their own answer and then pick it from the possible options.

- Experienced users tend to fixate directly on the resulting output right after they change the inputs from the control panels, while the inexperienced ones seem to gaze to the represented phenomenon, trying to realize the effect their changes had.

We also compare both groups' participants' visual activity with the expected one given by the tasks' designer. Except for the significant deviation in the inexperienced users' visual activity on the first task's third question, that is not paying attention to the pendulum's energy while changing its' mass, we also observe that both types of users tend to repeatedly re-read the questions or checking the answers while searching for the right answer.

Finally, by checking the students' answers on the worksheets to see if any of the previous deviations from the expected process could be responsible for a wrong answer, we conclude that inexperienced users reach to false conclusions about the correlation between the pendulum's mass and Potential Energy.

Chapter 7

Conclusions and limitations

In this study, we examined four students, grouped into two teams based on their experience in using computer simulations and their expertise in Physics, while they interact with a computer simulation to answer multiple choice questions, regarding the topic of oscillations. Both groups' participants should complete two tasks where they had to use a computer simulation to implement experiments and answer the corresponding worksheet's questions. Each one of the tasks was controlled in a different way. The first task was controlled the traditional way, that is using the mouse movement to move the screen cursor (mouse-control), while in the second one the cursor was controlled by the participant's pupil movement (eye-control). Our goal was to examine if by using eye tracking techniques we can uncover differences between the participants' behavior and to what extent these differences can affect the participants' success in answering the questions right.

Our findings indicate that using eye tracking can help us study the students' visual activity and reveal aspects of their behavior while interacting with the computer simulations to complete a given task, as it can give us clues for what may have gone wrong (i.e. in the way users gather information, what did they ignore, etc.). Eye tracking can also be successfully used as a tool for this human-computer interaction, as it provides the user with an innovative way to control the screen cursor.

We summarize our findings in the order of the experimental procedure we followed.

At first, we compared the users' behavior, based just on their experience in using computer simulations and their expertise on the Physics topic of oscillations, to find out how these differences affect it. We record and compare the amount of time they spend on each phase of the experiment. Our results show that:

- The users' experience does not affect their time needs to familiarize with a simulation as both experienced and inexperienced users spend about the same amount of time to get comfortable with it, in both cases.

- The users' experience affects the time they need to work with the simulations in order to conduct experiments and answer the questions. Experienced users generally spend less time to do so, although this also depends on the questions' nature and the actions they need to do to find the right answer.

- Both types of users spend less time familiarizing with the simulation than using it to conduct experiments when they were using a familiar control method, while when they are using a novel control method, they need approximately the same time for both.

Subsequently, we compare the novel method of interacting with the simulation, that is moving the screen cursor with their pupil movement (eye-control) with the traditional interaction method (mouse-control). Our results suggest that:

- Both types of users need more time to familiarize with the simulation when using the novel control method, compared to when using the traditional one.

- The time they spend working with the simulation is affected not only by the experiments' questions but by the control method as well, as we see that the amount of time participants spend for the same questions differs significantly when using different control methods.

- All users found the novel control method more difficult to use, but despite the difficulties and its' limitations, both types of users would prefer to use this innovative way to interact with the computer simulation, over the traditional one.

Finally, we focus on the users' visual activity and their gaze patterns during the experiment's process, trying to uncover differences between the two groups but also with the expected behavior. Our findings indicate that:

- Both types of users decide to begin the tasks by reading the worksheets' instructions and follow them strictly to proceed, rather than exploring the simulation and its' affordances by themselves.

- Experienced users tend to regress their gaze between the areas of interest more often while searching for the question's answers, compared to the inexperienced users.

- Inexperienced users tend to read the possible answers and try to prove one of them right, while experienced users first find an answer on their own and chose it from the given options.

- Experienced users tend to fixate directly on the resulting output right after they change the inputs from the control panels, while the inexperienced ones seem to gaze to the represented phenomenon, trying to realize the effect their changes had.

Our findings indicate that using eye tracking can help us study the students' visual activity and reveal aspects of their behavior while interacting with the computer simulations to complete a given task, as it can give us clues for what may have gone differently to what was expected (i.e. in the way users gather information, what they ignore, etc.). Eye tracking can also be successfully used as a tool for this human-computer interaction, as it provides the user with an innovative way to control the screen cursor.

All the beforementioned results should be further studied and verified by future research, as our sample is quite small. We should also keep in mind that the tasks and the worksheets were designed based on the eye-control method affordances and accuracy, which was very limited. Furthermore, the creation of areas of interest was quite cumbersome, as in some cases they overlapped each other. However, there is rapid development in eye-tracking technology that will lead to significant improvements in the future.

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Appendix

Worksheets

Pendulum Lab Worksheet

In the Pendulum Lab simulation, on the left half of your screen check the Period Timer box and show the Energy Graph.

Then set the Pendulum in motion from an angle of 50**°**.

Set the Period Timer on and measure the Pendulum's period. What is the measurement outcome?

- 1,6816 s
- 1,9092 s
- 1,7620 δ

In which point of his orbit the skater reaches his minimum Potential Energy (PE)?

- In 0° angle (equilibrium position).
- In 50° angle (maximum displacement).
- Between 0° and 50° angle (intermediate position).

Is it possible to increase the Pendulum's Potential Energy by changing its mass?

- Yes, by increasing his mass.
- Yes, by decreasing his mass.
- No, its mass does not affect its Potential Energy.

All answers should be based on your experiment outcome.

For more accurate measurements you can choose the slow option.

*Please do not change the Gravity, Length and Friction values.

Energy Skate Park: Basics Worksheet

In the Energy Skate Park: Basics simulation, on the left half of your screen check from the control panel the Bar Graph, the Grid and the Speed boxes.

Then set the skater in motion of a 4 meters height starting point.

In which point of his orbit the skater reaches his maximum speed?

- ◯ In 4m height (maximum displacement).
- ◯ In 0m height (equilibrium position).
- ◯ In 2m height (intermediate position).

In which point of his orbit the skater reaches his maximum Potential Energy?

- ◯ In 4m height (maximum displacement).
- ◯ In 0m height (equilibrium position).
- ◯ In 2m height (intermediate position).

Is it possible to increase the skaters Potential Energy by changing his starting point's height?

- ◯ Yes, by increasing his starting point height.
- ◯ Yes, by decreasing his starting point
- ◯ No, his starting point height does not affect its Potential Energy.

All answers should be based on your experiment outcome.

For more accurate measurements you can choose the slow-motion option.

Pendulum Lab simulation's Areas of Interest