Cognitive Strategies of Students in Virtual Laboratories (Eye Tracking Based Case Study)

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Abstract

The use of eye-tracking with the goal to help to reveal cognitive strategies while solving science (physics, biology, chemistry) problems is still quite rare, although it was successfully applied in many other research fields including human computer interaction and of course e-business. Usually eye-tracking is adopted to examine human visual attention. In general, eye fixation location reflects attention and eye fixation duration reflects processing difficulty and amount of attention. Besides, according some studies, scan path patterns exhibit individuals' cognitive strategies utilized in goal-oriented tasks. The eye tracking based research, presented in this article, was proposed, designed a realized by experienced researchers, who deal with neurophysiologic aspects of human computer interactions since 2002. In this paper they introduce the methodology (SSRD), and also revealed behavioural and problem solving patterns of students and teachers, while working with physics applets in virtual laboratories. Authors present individual differences as well as different problem solving patterns and even different cognitive strategies. They compare the effectiveness and efficiency of different individual approaches and bring some interesting conclusions.

1. Introduction

In order to improve human-computer interaction, eye-tracking measures and physiological reactions are used in combination to the context of navigation and the structure of actions to analyze emotional state of users in different contexts and/or their cognitive strategies, including behavioural and problem solving patterns.

Understanding affective reactions is essential to improve human-computer interaction and the design of systems. This assessment of user's motivational state can be used to evaluate interface design or to define interactive feedback or adaptation in systems. Thus the field of affective computing investigates and integrates many perspectives from psychology, neuropsychology and computer science. In the domain of e-commerce those techniques are being used informally to observe interactions during the design of systems, but more systematic methods are necessary to efficiently highlight important aspects of the interaction, or more importantly in order to design adaptive interactions.

The eye tracking technique has been typically adopted to examine human visual attention based on the eye-mind assumption. In general, eye fixation location reflects attention and eye fixation duration reflects processing difficulty and amount of attention (the longer the information is fixated, the more complex it is or the deeper it is processed).

Besides, scan path patterns exhibit individuals' cognitive strategies utilized in goal-oriented tasks [1]. Similar results were obtained by Lustigova and Dufresne [2].

The use of physiological reaction and eye-tracking methods with the goal to reveal cognitive strategies in science problem solving (physics, biology, and chemistry) is still quite rare. Although problem solving has deep cognitive underpinnings, and numerous physics problems have strong visuospatial components, most research in physics problem solving has not drawn from research in visual cognition. Recently, some researchers have begun to use eye movement data to gain deeper insights into how students solve certain type of problems ([6], [2]), how they read graphs [4], how they solve multiple choice problems [9] or to compare the differences between novices and experts on problem solving tasks ([3],[5],[6]). But, overall eye-tracking is a relatively new tool in the physics (and generally science) education research arsenal.

Tsai, Hou et al [9] within their research deal with visual attention while solving multiple choice science problems using eye/tracking analysis. They tried to compare the eye fixation duration between chosen and rejected options and between relevant and irrelevant factors students were offered with the task. But the methodology and the problem itself is connected to science education just very vaguely.

Mayer [10] deals with similar problems and provides a review of key studies that have used eye-tracking to investigate how eye fixation times in relevant areas of a diagram and performance on

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cognitive tasks may depend upon the learners' prior knowledge (knowledge effect), as well as the use of visual cues (signalling/cueing effect) and audio narration (modality effect) accompanying the graphic.

2. Description of a research problem

2.1 Research design

In eye tracking studies Small Sample research Design (SSRD) is often used (see [2]). The sample of size 6 (six male university students, aged from 19 to 21) was used for example in Tsai, Hou et al [9] study, while Pohl [4] had 5 participants in the pre-study and 36 in the main study. SSRD is used primarily to evaluate the effect of a variety of interventions in applied research, extensively in the experimental analysis of behaviour and applied behaviour analysis with both human and non-human participants. We decided to use SSRD because its sensitivity to individual differences, while group designs are sensitive to averages of groups. Sequential analysis on fixated Look Zones was further utilized to compare the solving patterns between successful and unsuccessful problem solvers.

2.2 Description of the experiment

The presented experiment was focused on the comparison of 1/visual attention (Eye tracking), 2/cognitive strategies (eye tracking, structured interview, observation) and 3/behavioural patterns (observation, eye tracking) of successful and unsuccessful solvers in the context of solving problem, represented by Davidson virtual laboratory physlet (available at http://webphysics.davidson.edu/). See figure 1.

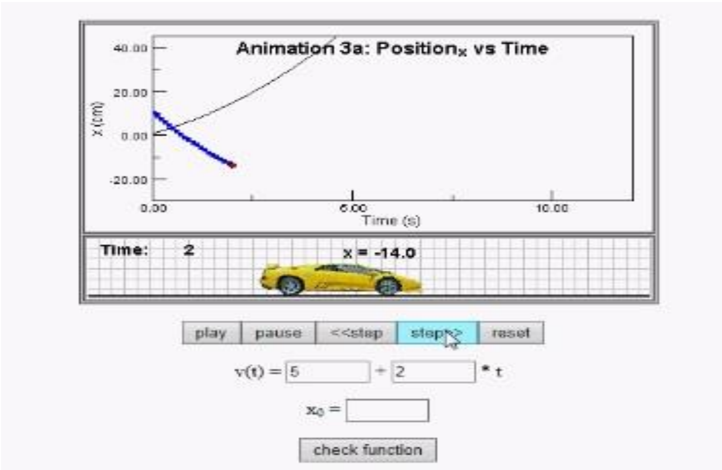


Fig.1. Davidson physlet, used in the experiment

Eye tracking was used to identify and quantify zones, which were more explored, the individual time of focus, sequential patterns while solving, time of fixations and scatter of heat map. Connected screen and person video recording was used for exploring cognitive strategies and behavioural and emotional reactions of the user. As a supportive method to reveal cognitive strategies we used pre and post interview.
As an explorative research we measured emotional reactions on the base of the skin conductivity and heart/ breathe rate measures. These measures were provided on volunteers among tested subjects, because both methods were found too invasive (participants used the word "bothering") and for that refused by the majority of experiment participants. The structured interview was used instead and simple questionnaire to obtain basic demographic data
The Tobii eye-tracking system was used ([7],[8]), and ISES system for physiological measurement. Data were recorded by both systems and were combined so they could be matched synchronously, along with interaction information.
A Java application was designed to ask the users to do specific tasks so the system could be trained to recognize each activity of the task model using only eye-tracking and interaction information. The training of the task structure recognition was done on one page where the different types of zones were defined.

3. Selected results

During the explorative research tens of research question were formulated. Here we present just selected, more general ones.

RQ 1: (competencies effect) On conceptual physics problems that require the use of a graph/diagram, the eye movements of experts differ significantly from the eye movements of laic solvers (scatter, cueing).

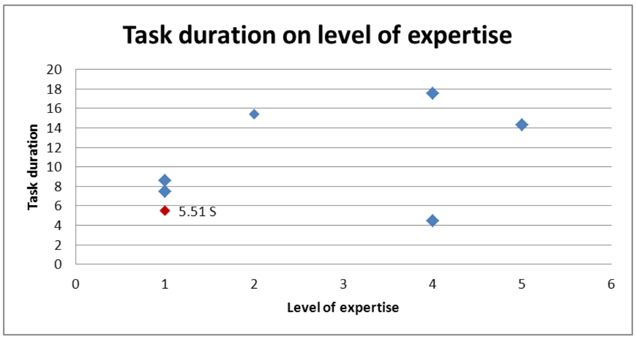
RQ 2: (cueing effect) There will be a visible difference among heatmaps of solvers with different cognitive strategies.

While between the records there are visible differences in lengths of particular records (see table1), and the ways they ended (success/failure) the final heatmaps are not so different. What differ are the cuing and the scatter. 3 different cognitive strategies were revealed among the participants: Analytical method, trial/error method (T/E) with different level of systemization and method of numerical bisection (NB), which was observed and identified as the most efficient method before, within a different group of participants.

Participant	1	2	3	4	5	6	7
Gender	F	M	M	M	F	F	M
Age	32	22	26	29	23	21	52
Education	PhD st, 4th year, physics	BC,MA stud, economy	BC, Social science	Second. school, hospitality	MA, social science	MA, math and physics (st)	Ass. Prof. math
Level of expertise	5	2	1	1	1	4	4
Task duration	14.29	15.42	7.42	5.51	8.55	4.42	17.52
Task fulfilment (success/failure)	F	Close to S	F	S	F	F	Close to S
Method used by participant	analytical	T/E	T/E	NB	T/E	T/E	analytical

Table 1: Basics statistics and description of participants

Fig.2. The graph of task duration versus the level of expertise.



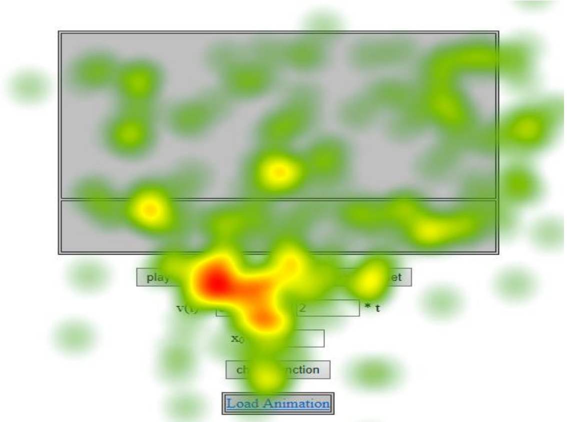


Fig.3. Heatmap of the only successful solver (time effective solution, numeric bisection method)

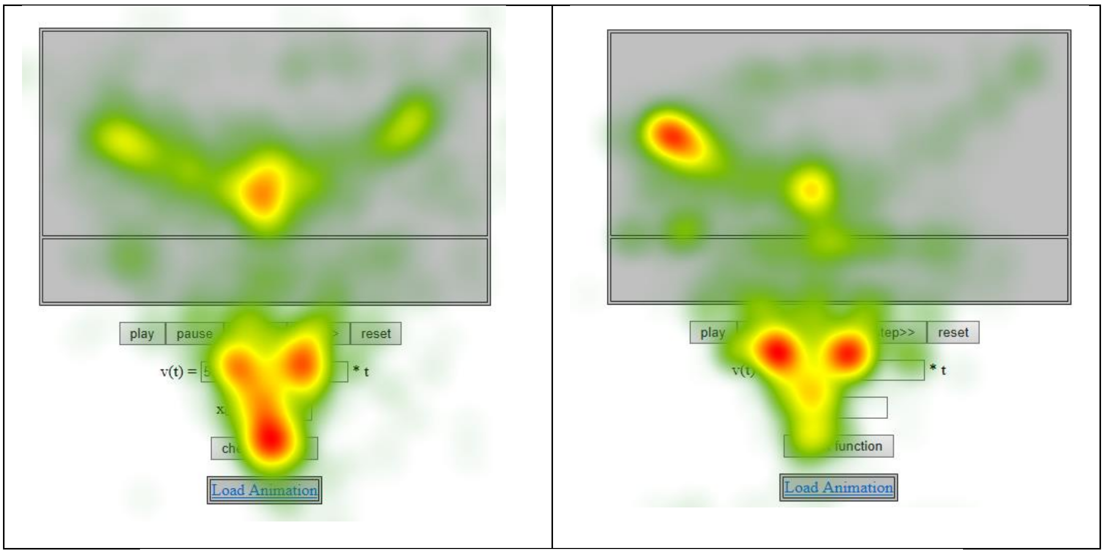


Fig.4. Heatmaps of unsuccessful solvers (a and b), analytical method.

Figure 4/a represents heat map of unsuccessful solver, who used time demanding analytical strategy (task duration 14,29min), while Figure 4/b represents heat map of unsuccessful solver, who used Trial/Error strategy, partially systemic, and frequent feedback. This strategy was applied by both participants (2 and 7), who were close to success. The similarity of their heat maps was very high.

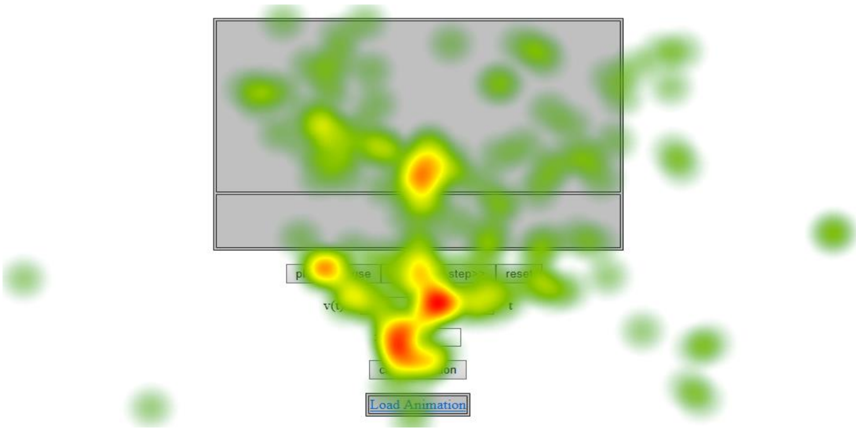


Fig. 5. Heatmap of unsuccessful solver, Trial/Error method, guessing.

4. Conclusions

Three different solving strategies were revealed. As the most efficient the numerical bisection method appeared, while analytical methods, used by participants with highest level of education within the subject studied, failed in both cases. The trial/error strategy results depended on the level of systemization and frequency of feedback operations.
The highest visual focus and the use of analytical strategies, represented by heatmaps with lowest spread, lead to failure, as well as highest spread. Additionally successful (or close to success) problem solvers focused more on relevant factors than irrelevant ones. Unsuccessful problem solvers experienced difficulties in decoding the problem, in recognizing relevant factors and quite often also problems with self-regulating and concentration (see figure 5).
Experts in the area, as well as highly educated people in different areas (e.g. economy), differ significantly in both (scatter, cueing) from laic solvers (scatter, cueing), but this difference is connected more to the strategy used then to the level of expertise. It is strategy what failed, not the level of expertise.

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