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Using Eye-Tracking Technology for the Analysis of Students' Subjective Views on Usefulness of Chosen Physics Formulas

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Abstract

This paper is the second part of research concerning students' view on usefulness of physics formulas. In the first part we examined subjective students' opinions on the usefulness of selected physics formulas from the school curriculum. No we concentrated on eye-tracking experiments. Students have assessed 16 of the most important physics formulas, chosen by physics teachers. For deeper understanding of student's choices on eye-tracking has been conducted. For 52 students divided on two groups: not participating in school competitions in physics and other natural sciences named “ordinary students” and participating in these competitions named “extraordinary students”, a relationship was observed between their eyes’ fixation time (divided into Area of Interest) on 16 displayed formulas and the frequency of recognizing these as useful. We compared also saccade duration time between these two groups of students. Physics contest winners found over 60% of these formulas useful, whereas the average students’ result was less than 30%. We observed a positive correlation between the number of eye-fixations on a given formula and the frequency of selection by the students as useful. Students that showed more interest in the selected subjects also perceived the areas of study presented by them to be much more useful to the society. It has also been concluded that the intention of choosing one’s profession within the area of a given subject depends on one’s interest in the subject.

Keywords: eye-tracking; eye-fixations; saccade; physics formulas; science education

Introduction

This article presents one of the uses of an eye-tracker, device for tracking human eye movement during solving a test task. Eye-tracker studies have been conducted in various centers in recent years (Lai, 2013, p. 90). They provide an analysis of eye movement while viewing static objects (e.g. works of art) or moving objects, during solving test or problem task (e.g. mathematical and physical test, chess problem) and during other decision making processes. Eye-tracking allows you to penetrate deeper into the essence of reasoning processes rather than seeing the final results of the decision itself.

Eye-tracking methods are often used in pedagogical sciences and didactics and are aimed at finding ways to improve teaching in school. One of the aims of this article is to search for the appropriated methods used to teach physics. During a thinking process in brain related with observation, concerning an emotional response to a perceived object or drawing presenting a problem, the eyeballs perform various, unaware movements. We do not look in the same way at the particular fragments of the image, but focus our attention on those parts that are more important for us at a given moment. The viewing time of these fragments is an important indicator of interest in a fragment of an image. Eye-tracker allows you to record two basic indicators describing image perception, i.e. fixations and saccades.

Fixations describe the time of stopping sight on a particular piece of the image and are interpreted as an indicator of interest in that fragment or indicator of difficulty in obtaining unequivocal perceptual information (Latmier, 1988, p. 437; Hauland, 2002, p. 230).

Saccades refer to the shift of the axis of vision from one fragment of the image to another. The total fixation time is approximately 90% of the total viewing time, and the saccades time represents the remaining 10% of the total viewing time (Francuz, 2013).

Methodology

Participants

The planned eye-tracking study required us establish the upper limit of the size of a research group at the level of several dozen people. There were 52 students aged 16, close to graduating from middle school, taking part in the experiment. The group consisted of 25 girls and 27 boys, of whom 34 were average in terms of their performance, and 18 were outstanding students, with achievements in provincial physics contest.

Procedure

The experiment was conducted in the Laboratory of Neuroeducation and Cognitive Teaching at The Pedagogical University of Cracow in Faculty of Mathematics, Physics and Technical Science.

In this part of the experiment, out of 16 formulas (see Figure 1), students were asked to choose the ones they claimed to be practically useful for them in life. The command was: “Several formulas in physics are presented below. Click the mouse and select those formulas that **YOU THINK** will be useful in your life”. They could select as many formulas as they wished, and they were not limited in time. The eye-tracker registered fixation parameters and saccadic movements of the examined eyes at a scanning frequency of 500Hz.

Several formulas in physics are presented below.
Click the mouse and select those formulas
that **YOU THINK**
will be useful in your life

1 $F = m * a$	2 $a = \frac{\Delta v}{\Delta t}$	3 $R_z = R_1 + R_2 + \cdots$	4 $s = \frac{at^2}{2}$
5 $E_p = m * g * h$	6 $v = \frac{\Delta s}{\Delta t}$	7 $W = F * s$	8 $T = \frac{1}{f}$
9 $E_k = \frac{mv^2}{2}$	10 $p = \frac{F_N}{S}$	11 $v_{śr} = \frac{s_{total}}{t_{total}}$	12 $\Delta E_w = W + Q$
13 $\rho = \frac{m}{V}$	14 $U = \frac{W}{q}$	15 $I = \frac{q}{t}$	16 $W = U * I * t$

SMI

Figure 1. 16 physics formulas of classical physics in the physics curricula

Eye-tracking apparatus

An advanced Senso Motoric InstrumentsHi-Speed 1250 eye-tracker, and software iViewX™ for recording a stream of data with 500 Hz time resolution, were used; the elements measured included coordinates (namely, coordinates *x* and *y* of the gaze position), pupil width (a relative and absolute measurement), and the parameters of saccades and fixations (Duchowski, 2007). The software provided for an analysis of the areas of interests defined by the researchers, attention maps (also called thermal maps, showing the focus of the participants' gaze) and other analyses (Jacob, Karn, 2003, p. 573). Spatial accuracy of the apparatus was 0.01°, the computing delay was less than 0.5 ms, and the system delay was less than 2 ms. The interface construction used in this system stabilized the position of the participant's head without limiting the field of vision.

Calibration and other operations, which ensured the results obtained were reliable and non-distorted, were made before each test (Ramanauskas, 2006, p. 65). The position of the chin support, among other things, was corrected so that the participants would be in a comfortable position with their eyes centered on the middle of the screen. Furthermore, the test was carried out with the same environmental conditions, including temperature, lighting and acoustic insulation, for all participants. The results were analyzed with the SMI BeGaze™ 2.4 software (2010).

Results eye-tracking study

In Figure 2 shows the division into AOI's (Areas Of Interest) and sample values eye-tracking in each AOI's for the exemplary student. These parameters are:

Sequence – the order in which the AOI was viewed regardless of time of the gaze fixation. This indicator is correlated with the parameter Entry Time;

Entry Time – time elapsed from the moment of the first fixation in the given area (time to first fixation);

Dwell Time – the average time spent gazing at the selected AOI (a sum of the fixations and saccades);

Heat Ratio – the number of participants that explored a given area;

Revisits – the average number of re-gazes (revisits) at a given area;

Revisitors – the number of persons who came back to a given area (the number of persons who viewed the area more than once);

Average Fixation – average fixation time on a given AOI interpreted as "I devote more time to viewing what is difficult for me";

First Fixation – the time elapsed from the moment of task presentation to the first gaze at a given area;

Fixation Count – the number of fixations on a given area which can be interpreted as indicating a greater interest in and the importance of the area.

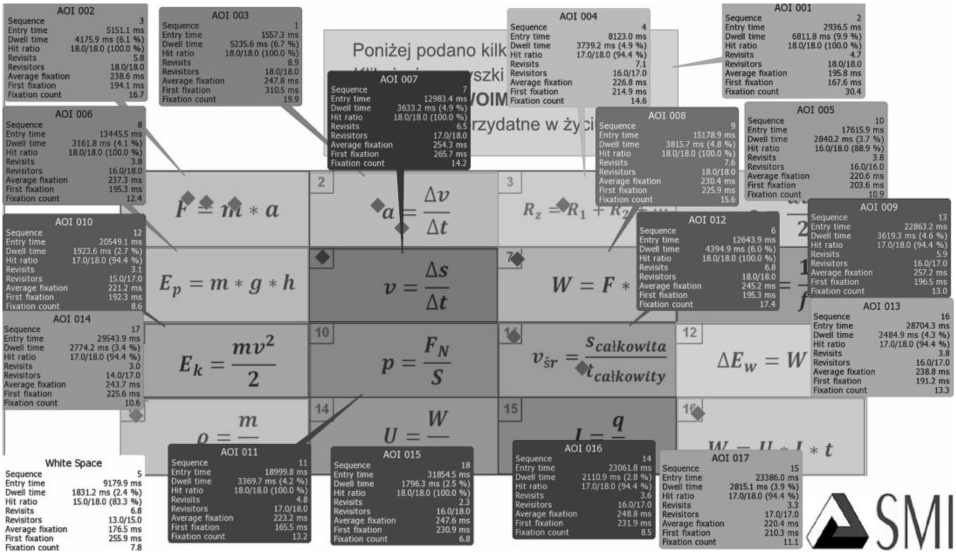

Figure 2. AOI (Area of Interest) parameters for one of the students

In Table 1 we show the means (Mean) of average fixation duration [μs], standard deviations (SD) of average fixation duration [μs] and standard errors of the mean (SEM) of average fixation duration [μs] for each AOI (Area Of Interest) for "extraordinary" and "ordinary" students, who choose Formula 6 as most important. Next we performed Students *t*-tests for two independent samples and showed empirical significant values (*p*-values) for the tests.

Table 1. Comparison of distributions of average fixation duration [μs] in each AOI's "extraordinary" for 15 students and 19 "ordinary" students who chose Formula 6 in the first place (as the most important)

No. of AOI	No. of Formula	EXTRAORDINARY			ORDINARY			p-value
		Mean	SD	SEM	Mean	SD	SEM	
AOI 1	text	202.203	26.040	5.974	196.891	24.535	6.335	0.546
AOI 2	1	238.025	64.969	16.775	231.209	41.760	9.580	0.713
AOI 3	2	255.389	70.956	18.321	224.731	55.234	12.672	0.180
AOI 4	3	244.594	66.185	17.689	239.891	65.210	14.960	0.841
AOI 5	4	246.322	54.475	15.109	246.154	74.416	17.072	0.994
AOI 6	5	241.436	51.210	13.222	243.330	68.071	15.617	0.927
AOI 7	6	263.889	114.176	29.480	231.711	58.680	13.462	0.333
AOI 8	7	237.032	49.018	12.656	230.141	55.077	12.635	0.707
AOI 9	**8**	**274.447**	**73.157**	**19.552**	**233.299**	**37.294**	**8.555**	**0.043***
AOI 10	9	251.314	144.687	38.669	251.685	132.030	30.290	0.994
AOI 11	10	224.479	47.840	12.352	206.633	57.142	13.468	0.336
AOI 12	11	255.333	59.404	15.338	272.698	73.694	16.907	0.452
AOI 13	12	245.836	91.991	23.752	250.749	64.149	14.717	0.862
AOI 14	13	266.491	77.895	20.112	219.276	65.877	15.527	0.074
AOI 15	14	252.051	85.463	22.067	221.569	52.214	11.979	0.238
AOI 16	**15**	**276.860**	**109.648**	**20.305**	**213.378**	**42.337**	**9.712**	**0.028***
AOI 17	16	227.728	38.442	10.274	222.358	70.738	16.229	0.782
white space		314.387	368.701	98.539	197.954	56.452	13.206	0.262

Note: * $p < 0.05$

Only differences between "extraordinary" and "ordinary" students for AOI 9 (Formula 8) and AOI 16 (Formula 15) are significant on the level 0.05.

In Table 2 are given the same coefficient for students who chose Formula 1 in the first place as useful.

Table 2. Comparison of distributions of average fixation duration [μs] in each AOI's for 11 students "extraordinary" and 11 "ordinary" students who chose Formula 1 as the most important

No. of AOI	No. of Formula	EXTRAORDINARY			ORDINARY			p-value
		Mean	SD	SEM	Mean	SD	SEM	
AOI 1	text	195.175	25.449	7.673	206.307	26.632	8.030	0.328
AOI 2	1	239.805	71.145	21.451	220.401	46.722	14.102	0.460
AOI 3	**2**	**258.552**	**76.687**	**23.112**	**199.251**	**29.445**	**8.576**	**0.026***
AOI 4	3	253.913	76.053	24.050	214.581	38.207	11.520	0.145
AOI 5	4	248.367	61.712	20.570	23.117	23.117	6.970	0.330
AOI 6	5	236.145	52.704	15.891	55.589	55.589	16.761	0.924
AOI 7	6	274.916	131.843	39.752	49.550	49.550	14.940	0.201
AOI 8	7	232.506	48.784	14.709	19.290	19.290	5.816	0.131
AOI 9	8	279.165	85.894	27.148	80.098	80.098	24.150	0.537
AOI 10	9	264.213	171.614	54.269	67.664	67.664	20.402	0.527
AOI 11	10	225.494	56.454	17.022	46.228	46.228	13.938	0.897
AOI 12	11	242.834	47.151	14.217	57.204	57.204	17.248	0.715
AOI 13	12	280.371	67.263	21.271	77.664	77.664	23.416	0.058
AOI 14	13	262.587	89.241	26.907	51.592	51.592	15.555	0.075
AOI 15	14	252.408	97.045	29.260	38.466	38.466	12.164	0.167
AOI 16	15	296.668	118.090	37.343	67.558	67.558	20.370	0.119
AOI 17	**16**	**237.117**	**31.729**	**10.033**	**42.758**	**42.758**	**12.892**	**0.013***
white space		335.526	417.271	125.812	180.407	61.229	18.461	0.249

Note: * $p < 0.05$

Only for AOI 3 (Formula 2) and AOI 17 (Formula 16), the differences between "extraordinary" and "ordinary" students are statistically significant at the level p = 0.05.

The correlations between the number of eye-fixations on a physics formula and the frequency of its selection by the students. **Figure 3a and Figure 3b presents the linear relationship between the number of eye-fixations on a physics formula and the frequency of its selection by the students as useful. In this case, we have observed a positive correlation between these variables.**

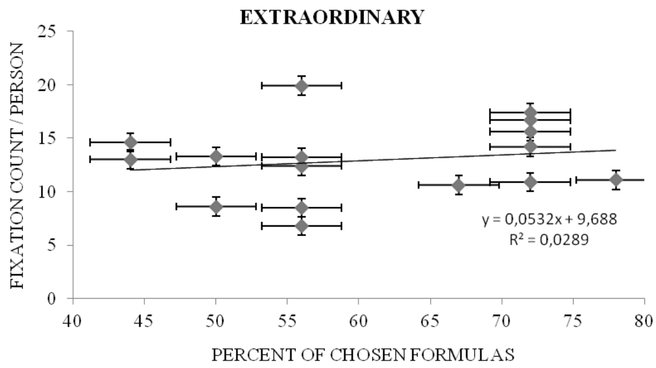

Figure 3a. The correlation between the number of fixation on a given formula of students and the percentage of students who found it useful for "extraordinary" students

In students who won the provincial physics contest no significant dependency has been observed between the number of eye-fixations on the physical formula (y), and their assessment of its usefulness (x). For these students $y = 0.05x + 9.67$, and $R = 0.17$.

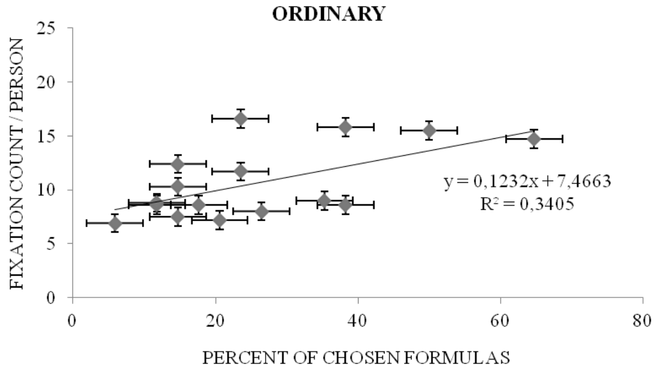

Figure 3b. The correlation between the number of fixation on a given formula of students and the percentage of students who found it useful for "ordinary" students

For the “ordinary” students the relationship is $y = 0.12x + 7.47$, and R = 0.58. The fixation time on the selected area of interest usually correlates highly with the fixation number. We have analysed in detail the visual paths and heat maps of all participants of the eye-tracking experiment.

In addition to fixation, the second group of parameters referring to the trajectory of eye movement are saccades – the shift of axes of vision from one position to another. The saccade duration total represents about 10% of the total viewing time of the image, while the saccade count is equal to the number of fixation points minus 1. For the statistical analysis we take the saccade duration average, ie. ratio the saccade duration total to saccade count (Franuz, 2013).

Comparing saccade duration average [ms] “ordinary” and “extraordinary” students we noticed significantly greater value for “extraordinary” students (p-value = 0.014). Figure 4 shows the saccade duration average for two group: “ordinary” and “extraordinary” students.

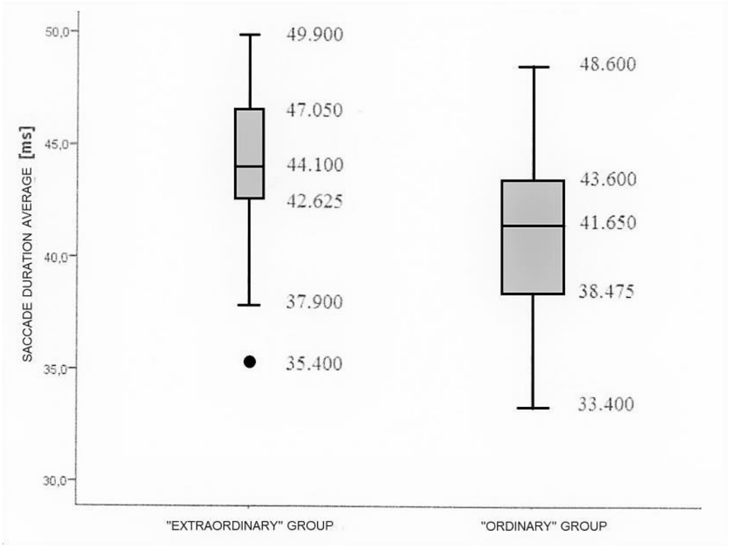

Figure 4. The saccade duration average for two group: “extraordinary” and “ordinary” students

Median for “extraordinary” students is 44.100 and for students in the “ordinary” group is 41.650. Skewness in both groups is negative and is -0.696 for students “extraordinary” and -0.231 for students “ordinary”.

Discussion and conclusions

Our choice as to what is important or significant depends on our knowledge, experience and also on many subjective factors (Kahneman, 2011). In our research, we have used cutting-edge techniques, allowing for tracking eye movements of the people examined while making choices. The analysis of correlations between the fixation count on a given formula and the number of formulas chosen as significant has yielded the most interesting results. The fixation count on a given formula is of course proportional to total dwell time. The time of particular fixations equalled several hundreds of milliseconds. In average students, with a low interest in physics, we have discovered a positive correlation (R = 0.6). The formulas inspected for a longer period of time, were chosen more frequently. In the winners of physics contests, the correlation was near zero. The students with greater knowledge of the subject made choices on the basis of their experience in the usage of the formulas and not on their visual form. It clearly confirms the theory of Norton and Stark (Norton, 1970, p. 349; Norton, Stark, 1971, p. 308).

The change in the reference system and viewing some aspects of teaching from the perspective of a student, and not only the teacher, have proved to be a significant research strategy. In one of our previous studies, we stated that in the early stage of teaching physics there is a vast discrepancy between the number of students claiming to be interested in physics and those perceived to be interested in the subject by their teachers (Błasiak, Godlewska, Rosiek, Wcisło, 2012, p. 565). It led us to implementing changes in the training of the prospective teachers. A look at the usefulness of physics formulas in the school curriculum from the point of view of the students calls for further improvement in the methodology of mathematical description of natural phenomena or to revision of the school curricula. We must always strive for a better implementation of the principle "Non scholae, sed vitae discimus" ("We learn not for school, but for life").

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