Author(s): Viiri, Jouni; Kekule, Martina; Isoniemi, Jenna; Hautala, Jarkko

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EYE-TRACKING THE EFFECTS OF REPRESENTATION ON STUDENTS' PROBLEM SOLVING APPROACHES

Jouni Viiri[1], Martina Kekule[2], Jenna Isoniemi[1] & Jarkko Hautala[1]

[1]University of Jyväskylä, [2]Charles University Prague

ABSTRACT

This study used an eye-tracking method to explore students' approaches to solving the same task in different representations and the differences between students who answered correctly and those who answered incorrectly when solving the problems. Thirty-one upper secondary students took part in the study. According to the results of this study, the representation has a slight effect on students' problem solving processes. Students with the incorrect answers paid more attention to the parts of the tasks with information irrelevant to determining the solution to the task.

INTRODUCTION

Problem solving is an important interest of physics education research. There are numerous different definitions what problem solving means (e.g. Maloney, 2011). We are interested in qualitative problems exploring students' conceptual understanding. A well-known qualitative study is the Force Concept Inventory (FCI) (Hestenes, Swackhamer, & Wells, 1995). Each FCI-item includes a verbal question and five verbal multiple-choice alternatives, of which one is correct and four are incorrect. FCI test result gives information about student's understanding of the force concept, but since it is a paper-pencil test, it does not directly explore student's problem solving approach.

To uncover students' approaches, in recent years problem solving has been investigated also by the eye-tracking method (e.g., Tai, Loehr, Brigham, 2006). The method is based on the eye-mind assumption (Just & Carpenter, 1980), which suggests that eye movements provide a dynamic trace of where attention is being directed. Although there is not an absolute certainty that eye movement is linked to the attention, eye movements very often are related to the change of attention (Hoffman & Subramaniam, 1995). Tracing attention of watching person allows us to get deeper insight into his or her problem solving strategies. The method has been successfully employed in exploring learning processes in literacy, multimedia learning, science problem solving strategies, and searching for differences among a group of watchers–for example, between novices and experts (Lai et al., 2013). Gegenfurtner, Lehtinen and Säljö (2011) observed that experts are able to collect information about the parafoveal area and are better able to distinguish between important and irrelevant information. Thus, the experts do not have to create fixations of all the information given in the task, but are capable of briefly viewing the relevant information in the task.

Most eye-tracking studies in physics education were interested in mechanics. Some studies focused on students' strategies for solving tasks of FCI (Madsen, Larson, Loschky, & Sanjay Rebello, 2012; Kozhevnikov, 2007; Ohno, 2016). Madsen et al. (2012) examined the differences in eye-tracking data for students who answered correctly and those who answered incorrectly the FCI-test items. Moreover, they were focused on examination of amount of time which students spend on areas relevant or irrelevant for successful solution. They discovered that students who answered the task correctly had looked at the areas that are relevant for solving the tasks more than the other students did. In addition, the students who answered incorrectly spent more time viewing the attention-attracting areas than the students who answered correctly. Kekule (2014) focused on the qualitative analysis of heat maps of students who solved problems with kinematic graphs.

In the FCI test questions are in verbal form. Researchers have been interested of students problem solving when problems are posed not only in verbal form but in different representations, e.g. text, graph, or table (Treagust, Duit & Fischer, 2017). Nieminen, Savinainen and Viiri (2010) studied students' understanding of different representations with the representational variant of the FCI test (the R-FCI test). The R-FCI is based on nine items taken from the FCI. For the R-FCI, the original verbal multiple-choice alternatives of the FCI items were redesigned using various representations graphs, vectors, motion maps, or bar charts (see two examples in Figure 1). With R-FCI researchers can evaluate students' representational consistency in answering triplets of isomorphic items in the context of forces. Nieminen et al. (2010) found that in some tasks, students' understanding was statistically significantly different when posed in different representations.

RESEARCH AIM AND QUESTIONS

Since Nieminen et al. (2010) could not explain the found differences in solving the R-FCI test items, our aim was to use eye-tracking in exploring the differences in students' approaches to solving the same task in different representations. Our research questions are:

1. How does the problem representation affect students' problem solution process?

2. How do the students with correct answer and the students with incorrect answer differ in solving the problems?

For both the questions we used eye-tracking method, so that operationally, we observed students' attention allocation during students' solving the tasks.

METHODS

Data collection

Participant students were chosen from an upper secondary school in central Finland. They were studying the first and fifth physics course (Opetushallitus, 2003), both of which deal with mechanics. Data collection was carried out in October 2016. The test involved a total of 39 students, 12 of whom were from the fifth course and 27 of whom were from the first course; they ranged in age from 15 to 19 years. Eight students' gaze-tracking data was incomplete, e.g. the signal from the device was lost during the task, thus it could not be used in the study. The data, therefore, is from a total of 31 test subjects.

In this study, we analysed students' problem solving abilities in three tasks (T22, T24 and T26 from the study of Nieminen et al. (2010) with an eye-tracking device. The topic of all test questions was mechanics. The test basically had three different questions, but all of them were presented in three different representations: verbal, graphic, and motion map. Thus, the students completed nine tasks altogether. Only two items of the R-FCI are presented here (Figure 1) in order to preserve the confidentiality of the original FCI items. All task stems appeared in written form.

The eye-tracking device used in this study was the SMI RED250mobile. Prior to data collection, the eye-tracking unit was set to 250 Hz sampling frequency, the fixation minimum period was 50 ms, and saccade was determined by the speed of at least 40°/s movement of the eye.

The students completed the test independently on the computer. They were sitting at distance 65 cm far from the computer. Before using the device, it was calibrated and validated with five fixation points to determine the position of the eyes of the participating student. Recalibrations were done if the validation indicated larger than 0.5° measurement error. The multiple-choice questions appeared on the screen one by one. Students selected the alternative they thought to be the correct answer with the mouse, after which a new question appeared on the screen.

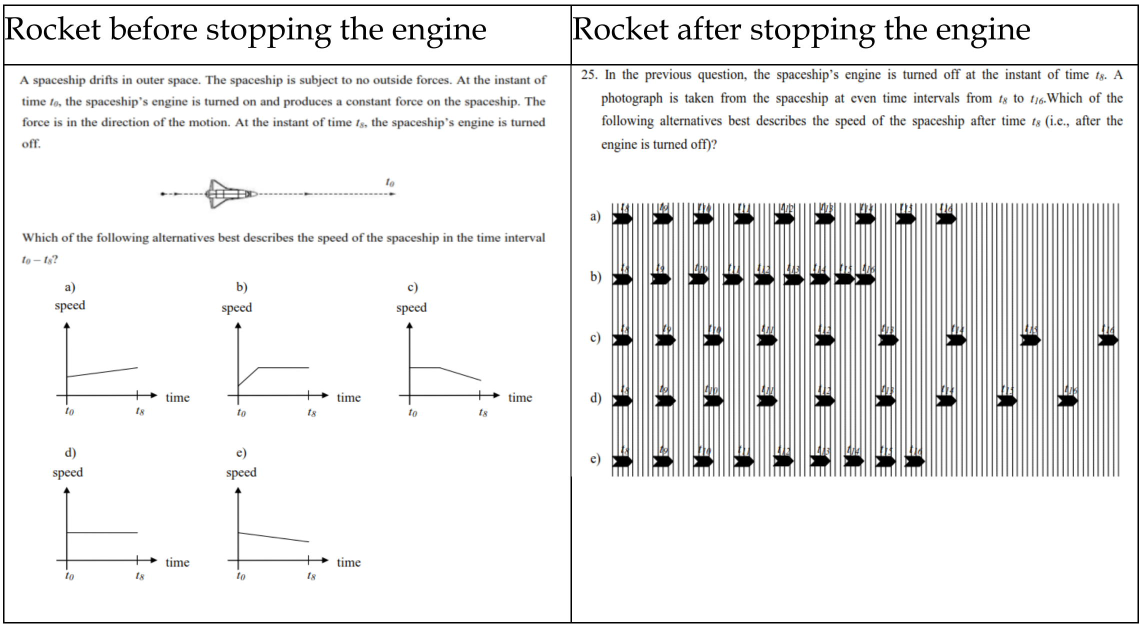

Figure 1. Example items from the R-FCI test, one in graph representation and the other in motion map representation.

Data analysis

First, we analysed how students solved the problems: that is, which alternative they chose. For the analysis of the eye-tracking data, we created the areas of interest (AOIs) with the SMI Experiment Center software. In every item, the stem (question) and each multiple-choice alternative was a separate AOI. Figure 2 shows what the AOIs look like.

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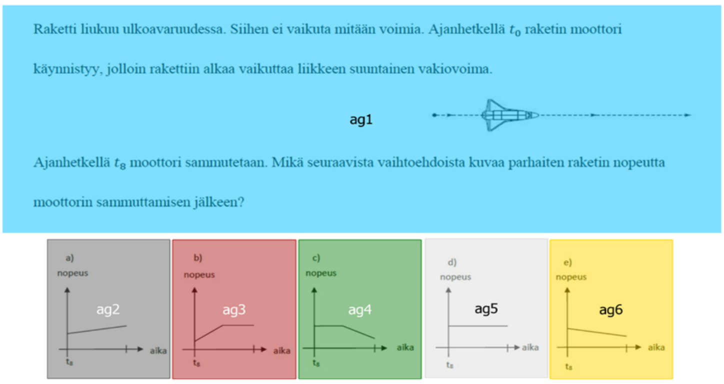

Figure 2. Areas of interest in the questions.

Test subjects did not see the AOIs at any stage of the test. For the qualitative analysis of eye-tracking data, we generated heat maps and AOI sequence charts with SMI BeGaze software. Heat maps show visually how much a subject has viewed certain areas, words or images when solving the problems. With the AOI sequence charts we receive information about how long and in what order students viewed the stem and the various options.

RESULTS

The task focusing on understanding Newton's 2nd Law ('woman pushing a box') was correctly answered by very few students. Because of our aim was to compare groups of students who answered either correctly or incorrectly, this task was not analysed further, and only the results for tasks about the rocket are presented in the paper. Table 1 shows how many students chose each of the different alternatives in each question. The questions are in the same order the students saw them on the computer (now excluding the task 'woman pushing the box'). The task order was chosen so that the same task in different representations was not expressed twice successively.

Heat map comparison

The eye-tracking data was used to make heat maps for students who had answered the item correctly and for students who had answered incorrectly. Figures 3, 4 and 5 show the heat maps of all students with either correct and incorrect solutions in verbal, graph and motion map representations of the task asking the rocket speed before or after stopping the engine. Number of students having a correct or incorrect answer is in Table 1.

Table 1. Number of students having a correct or incorrect answer. (rocket before = item rocket before stopping the engine; rocket after = item rocket after stopping the engine)

Item	Representation	Correct answers (n)	Incorrect answers (n)			
rocket before	graph	a (12)	b (6)	c (2)	d (10)	e (1)
rocket before	verbal	d (9)	c (0)	a (1)	b (11)	e (10)
rocket after	graph	d (11)	a (1)	b (1)	c (6)	e (12)
rocket before	motion map	c (12)	a (12)	b (2)	d (5)	e (0)
rocket after	motion map	a (9)	b (8)	c (4)	d (3)	e (7)
rocket after	verbal	e (17)	a (5)	b (7)	c (1)	d (1)

Verbal representation

In the verbal representation, the students who gave the correct solution paid almost as much attention to every alternative (Figure 3) excluding the correct alternative. Similarly, the students with incorrect solution have looked every alternative almost equally. In both tasks–before or after stopping the engine–students with correct answers paid somewhat more attention to the words 'outer space' and 'does not affect anything' in the stem than did students with incorrect answer. Students who answered incorrectly paid more attention to variable values t_0 and t_8. The importance of the variables in solving the task is minimal because they only tell the time period during which to consider the rocket speed. These students have also paid more attention to the figure of the rocket, which is also not relevant to solve the task.

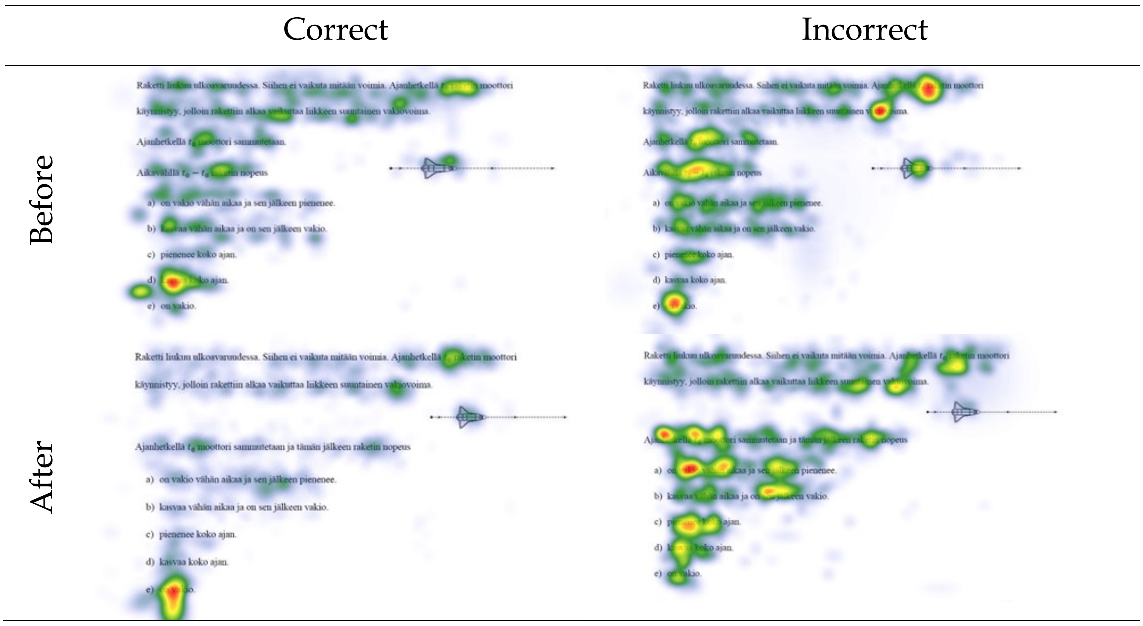

Figure 3. Heat maps of all students who answered either correctly or incorrectly in the items of the speed of the rocket before and after stopping the engine in verbal representation.

Graph representation

Based on the heat maps of the graph representation, it seems that students with correct answers found the answer easily (Figure 4, red spot in a (before) and d (after)). They did not have to carefully go through every answer option. The heat map provides information on students' misconceptions. In the task 'rocket after stopping the engine', students with the incorrect answer have been reading most the alternative e, that is, speed slowing motion. The second most common incorrect option was c (6 students) and it has been viewed the most. Students may choose this alternative if they have a misconception that first the object moves for a while in constant motion (rocket 'remembers' the force) and then starts to decelerate. As in the verbal representation, students with the incorrect answer have paid more attention to the symbols of time than the students with correct answer.

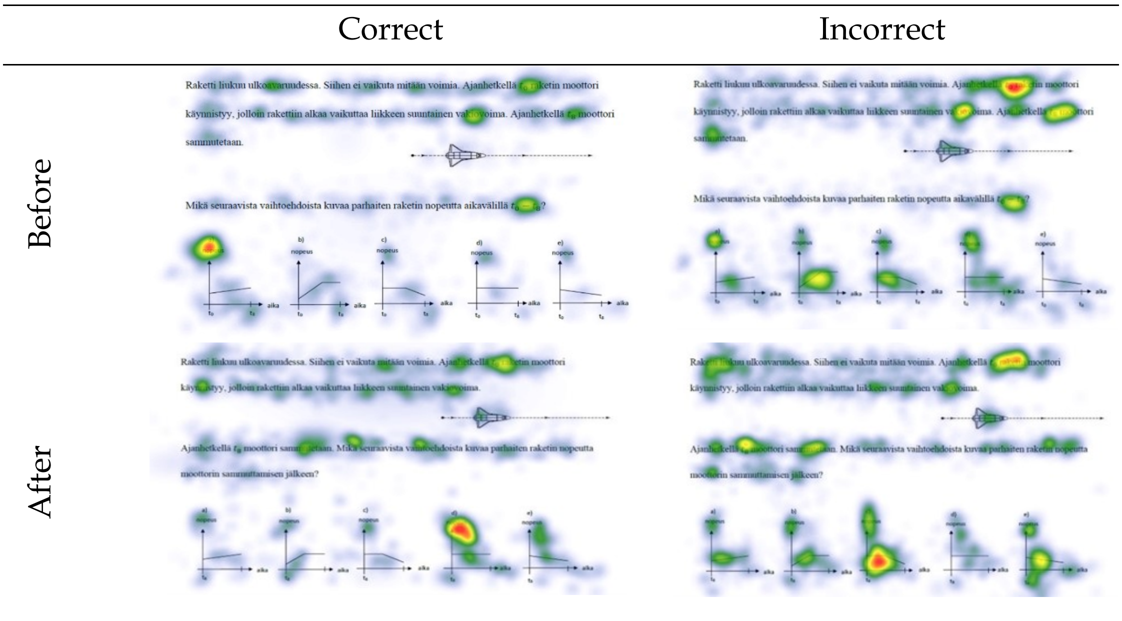

Figure 4. Heat maps of all students who answered either correctly or incorrectly in the items of the speed of the rocket before and after stopping the engine in the graph representation.

Motion map representation

In the motion map representation (see Figure 5), students with the correct answer were interested in other options as well. For the task 'rocket after stopping the engine', student except correct alternative a also viewed the alternatives c, d and e. They probably understood how to apply the law of inertia in this task and were able to omit option b immediately. They perhaps looked at the beginning the other options to ensure that they did not reflect uniform motion. For the task 'rocket before stopping the engine' students with the correct answer have been looking a lot on alternatives c and d. This could be explained by the fact that quickly seen both motion maps appear describing the constantly accelerating motion. To get the correct answer, the student must, however, compare the intervals between the points to note that d-alternative describes motion in which the rocket is first accelerating, and then in uniform motion. Students who answered incorrectly went through all the alternatives. Students have been reading more the stem of the task rocket before the engine stops. This might be because this tasks preceded the task after engine stopping. However, if students consider the finding of the correct answer challenging, it is natural that the student looks at the assignment many times to be sure that he/she has understood the assignment, and that he/she has not overlooked anything.

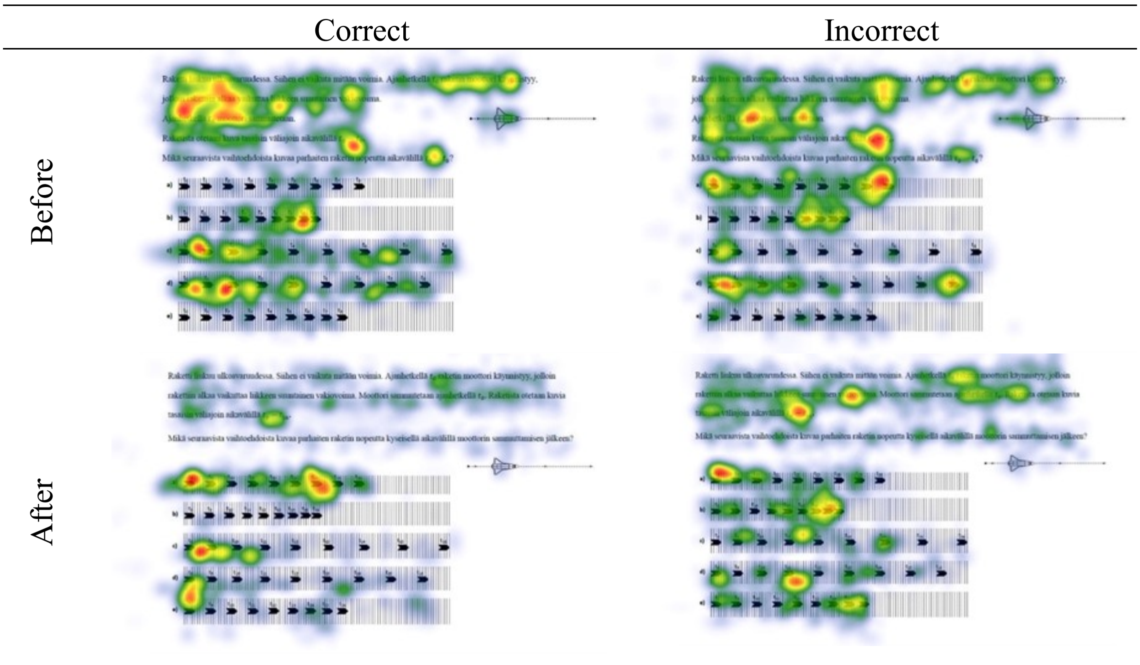

Figure 5. Heat maps of all students who answered either correctly or incorrectly in the items of the rocket speed before and after stopping the engine in motion map representation.

AOI sequence charts

Complementary to the heat maps the AOI sequence chart shows the temporal order in which AOIs were hit by a particular subject. Here we show two case examples, AOI sequence charts of one student with correct solutions and another student with incorrect solutions.

From the figures in Figure 6, we can see that a student with the incorrect solution viewed different AOIs many times in the verbal representation. In contrast, the student with correct solution viewed each AOI about once. The student with the correct solution also read the stem longer and after that looked for the solution. Instead, the student with incorrect solution has repeatedly reread the stem.

In the motion map representation, both the student with the correct answer and the student with the incorrect answer looked at each alternative many times. This is in accordance with the heat map information of the task. In this case, the student with the incorrect answer had looked at the stem very long, and also the total time for solving the task was long. In the graph representation the solution approaches were similar (space limit excludes having the figures here).

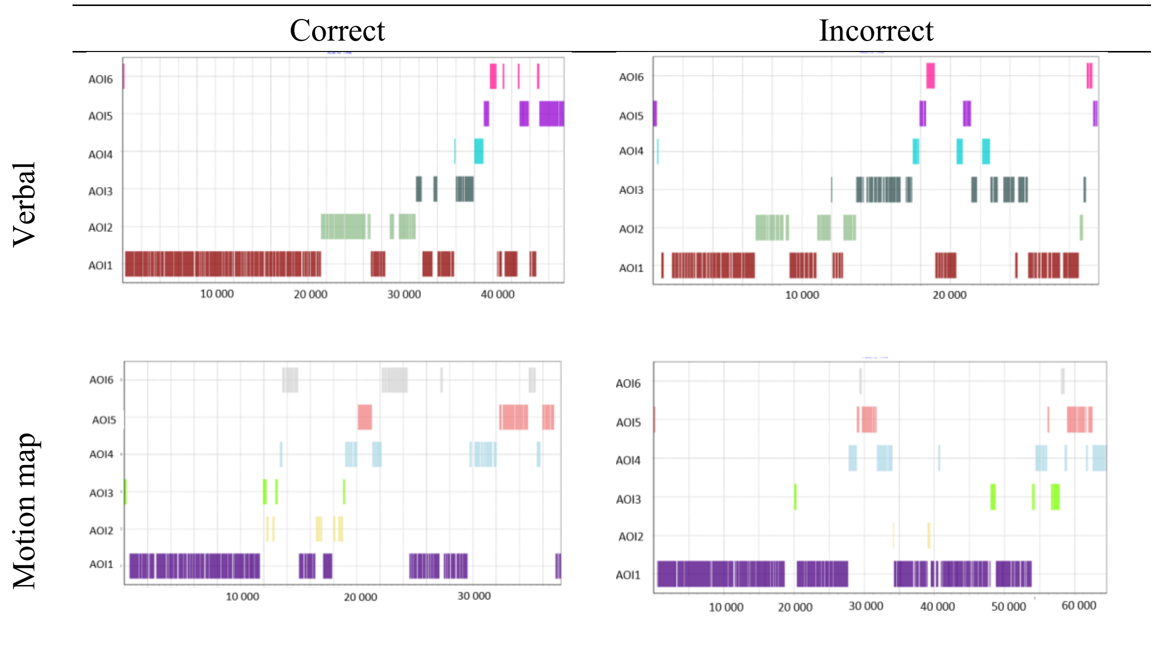

Figure 6. AOI sequence chart of a student solving task 'rocket before stopping the engine'. Horizontal axis shows viewing time (ms) and vertical axis shows AOIs. Stem AOI is at the bottom.

CONCLUSION

Our first research question was to explore the differences among students' approaches to solving the same task in different representations. Items in motion map representation produced more problems for students than the items in graph representation. In the motion map task, it was difficult to obtain enough information to arrive at the correct answer at a quick glance. In addition, many options on the motion maps look similar, so the students have to concentrate on viewing the motion maps to find the correct answer. For this reason, students were not able to select the correct answer on the motion maps without also looking at the other options. Based on the result of the AOI sequence charts, students with the correct answer on the motion map representation looked at all alternatives many times.

The difference between students' processes in the verbal and graph representations is probably due to the fact that in the verbal form, students had to read the alternatives before receiving enough information to select the correct solution. In contrast in the graph representation the information is encoded in the shape of the graph so students can quickly receive information about the shape and further decode the gained information without even looking at it (Cleveland, 1994).

The number of correct answers in the verbal representation of the rocket tasks differed. In verbal representation, students can give the answer that best describes their understanding, whether it is correct or incorrect, without any other knowledge about the encoding of information that appears in the other representations. Therefore, we cannot say that verbal representations have a general impact on how well students are able to solve the task correctly.

Our second research question was to explore differences between students who answered correctly and students who answered incorrectly when they solved the problems. There is a clear difference in the viewing of tasks between these student groups. Students with correct answers paid somewhat more attention to the relevant part of the stem, suggesting that these students had a better understanding of the relevant assumptions for solving the task. This is in accordance with the previous studies (e.g. Gegenfurtner, et al., 2011). This partly explains the fact that the students with the correct answer do not go systematically through all the answer options but quickly browse them to find the correct one.

Heat maps show that the students with incorrect solutions more frequently view the irrelevant part of a task, such as the variable symbols, figure of the rocket or alternatives that can be connected with misconceptions. This is in line with previous studies showing that novice students pay attention to irrelevant and gaze-attracting parts (Madsen et al., 2012).

Using the eye-tracking method allows us to follow students' way to distribute their attention. This knowledge is important for teachers to better understand students' processes when solving problems, and it could even be used in teacher training to help teachers be ready to scaffold students. The results of this qualitative study needs to be confirmed by quantitative study focusing also on student's explanations of their viewing behaviour. In any case, this study gave us relevant qualitative information to plan a new study with more tasks and participants. This enables also the use quantitative data analysis.

REFERENCES

Cleveland, W. S. (1994). *The Elements of Graphing Data*. Hobart Press, New Jersey.

Gegenfurtner, A., Lehtinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualization. *Educational Psychology Review*, *23*, 523-552.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force Concept Inventory. *The Physics Teacher, 30*, 141-158.

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perceptual Psychophysics*, *57*, 787–795.

Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, *87*, 329-354.

Kekule, M. (2014). Students' approaches when dealing with kinematics graphs explored by eye-tracking research method. *Special issue of European Journal of Science and Mathematics Education*, ISSN 2301-251X. 108-117.

Kozhevnikov, M., Motes, M., & Hegarthy, M. (2007). Spatial visualization in physics problem solving. *Cognitive Science*, *31*, 549–579.

Lai, M., Tsai, M., Yang, F., Hsu, Ch., Liu, T., Lee, S., Lee, M., Chiou, G., Liang, J., & Tsai, Ch. (2013). A review of using eye-tracking technology in exploring learning from 2000 to 2012. *Educational Research Rev*iew, *10*, 90-115.

Madsen, A. M., Larson, A. M., Loschky, L. C., & Sanjay Rebello, N. (2012). Difference in visual attention between those who correctly and incorrectly answer physics problems. *Phys. Rev. Special Topics – Phys. Ed. Research*, *8*, 010122.

Maloney, D. (2011). An Overview of Physics Education Research on Problem Solving. http://www.compadre.org/per/document/ServeFile.cfm?ID=11457

Nieminen, P., Savinainen, A., & Viiri, J. (2010). Force Concept Inventory-based multiple-choice test for investigating students' representational consistency. *Physical Review Special Topics – Physics Education Research*, *6*, 020109.

Ohno, E., Shimojo, A., & Iwata, Mi. (2016). Analysis of Problem Solving Processes in Physics Based on Eye-Movement Data. In Proceedings of GIREP 2015, University of Wroclav, pp. 64-70.

Opetushallitus (2003). Lukion opetussuunnitelman perusteet 2003, Vammalan Kirjapaino Oy, Vammala 2003.

Tai, R. H., Loehr, J. F., & Brigham, F. J. (2006) An exploration of the use of eye-gaze tracking to study problem-solving on standardized science assessments. International Journal of Research & Method in Education, 29, 185-208.

Treagust, D.T., Duit, R., & Fischer H. E. (eds.) (2017). Multiple representations in physics education. Springer.