Chapter 12
Students' Understanding of Diagrams in Different Contexts: Comparison of Eye Movements Between Physicists and Non-physicists Using Eye-Tracking

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Introduction

The understanding of graphs and their adequate handling plays an important role in physics and in the other STEM (Science, Technology, Engineering, and Mathematics) disciplines. Graphs serve to simplify the representation of complex relationships, and to facilitate the exchange of information between individuals as well as the development of conceptual knowledge in a domain (Curcio, 1987; Freedman & Shah, 2002; Pinker, 1990; Strobel et al., 2018). They are also important in everyday

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life, because information in newspapers, on the Internet and TV is often conveyed through graphs. Student understanding of graphs has been investigated in many studies in physics education, mathematics education, and educational psychology. For example, McDermott et al. (1987) reported about dominant student difficulties in connecting graphs to physical concepts: discriminating between the slope and height of a graph, interpreting changes in height and changes in slope, relating one type of graph to another, matching narrative information with relevant features of a graph, and interpreting the area under a graph. A few years later, Beichner (1994) developed the Test of Understanding of Graphs in Kinematics (TUG-K), which became one of the most widely used PER assessment instruments and which includes well-examined student difficulties in the context of graphs. This test was recently modified by Zavala et al. (2017). More recently, a number of studies investigated and compared university students' understanding of graphs in mathematics, physics, and other contexts (Christensen & Thompson, 2012; Planinic et al., 2012; Wemyss & van Kampen, 2013; Planinic et al., 2013; Ivanjek et al., 2016; Bollen et al., 2016; Ivanjek et al., 2017). While most studies explored student interpretation of graph slope, there are only a few studies on student understanding of area under a graph. Recent studies using parallel (isomorphic) problems in mathematics, physics, and other contexts have shown that parallel problems with added context (physics or other context) were more difficult than the corresponding mathematics problems (Planinic et al., 2012; Wemyss & van Kampen, 2013; Planinic et al., 2013; Ivanjek et al., 2016, 2017). This suggested student difficulties with transfer of knowledge between mathematics and physics (or other contexts). It was found that students solved questions on water level vs time graphs better than the corresponding questions on distance vs time graphs, although they had never encountered former graphs in the formal educational setting. The analysis of students' responses and the categorization of their strategies revealed that they used similar correct and incorrect strategies regardless of country (Ireland, Belgium, and Spain in Bollen et al., 2016; Croatia and Austria in Ivanjek et al., 2017) or the level of mathematical proficiency (algebra-based or calculus-based physics courses).

Many researchers investigated students' ability to transfer mathematical skills to a different context such as physics or chemistry. The results have shown that direct transfer rarely occurs, i.e. students rarely apply problem solving strategy learned in a particular context (mathematics) to another context (e.g. physics). Obviously, students' ability to transfer certain mathematical skills depends on their possession of the required mathematical knowledge. Some researchers reported that the main cause of students' difficulties with transfer is a lack of the mathematical skills to be transferred (e.g. Potgieter et al., 2008; Hoban et al., 2013). However, studies on student reasoning about graphs in different contexts have shown that students who successfully solve problems in (purely) mathematical context, often fail to solve corresponding problems in physics or other contexts (Planinic et al., 2012; Wemyss & van Kampen, 2013; Planinic et al., 2013; Ivanjek et al., 2016, 2017). Some authors, such as Bransford and Schwartz (1999), suggested departure from studies that are looking for direct transfer to a broader view on transfer which includes students' "preparation for future learning". This perspective assumes that students who do not directly apply prior knowledge in a new context, might still be able to adapt prior knowledge and use it as a support in new learning. Hammer et al. (2005) discussed a resources framework as basis for this broader view of transfer. When students learn a new idea, they activate existing resources in new combinations, and activation of the resources depends on the context and the provided scaffolding. Indeed, a previous study on student reasoning about graphs in different contexts reported some examples of transfer of knowledge in the sense of preparation for future learning, such as using dimensional analysis (acquired in physics) in solving problems in other contexts (Ivanjek et al., 2016).

All previous studies on the influence of context on performance were conducted on physics students, so we decided to additionally explore non-physics students' understanding of graphs in both physics and everyday contexts (Klein et al., 2019; Susac et al., 2018). For the everyday context we have chosen the finance context that all students are familiar with. In addition to students' scores, we used eye tracking in our studies to investigate where students allocate visual attention during problem solving. Eye tracking has proven to be a powerful method that complements previous research with a data source on visual attention, i.e. how students extract information from graphs. This yields process data of learners while they solve problems with graphs. The measurement of eye movements is an increasingly used method in the educational sciences. There are a number of eye-tracking studies on understanding of graphs (Kozhevnikov et al., 2007; Viiri et al., 2017; Kekule, 2014; Carpenter & Shah, 1998; Goldberg & Helfman, 2011). In some studies kinematics graphs were used to investigate graph comprehension (Kozhevnikov et al., 2007; Viiri et al., 2017; Kekule, 2014), otherwise different graphs with everyday contexts were employed (Carpenter & Shah, 1998; Goldberg & Helfman, 2011). In the context of understanding kinematics graphs, Madsen et al. (2012) have shown that students who answer a question correctly focus longer on specific relevant areas of a graph such as the axes. Their findings also suggest that previous experience with a topic can increase the focus on the important regions (Madsen et al., 2013). Conversely, it can be assumed that learning difficulties and misunderstandings in the use of graphs (e.g. point- interval confusion; Leinhardt et al., 1990), which are well studied and well known in the literature, are reflected in certain eye-movement patterns and attention distributions that are shifted to conceptually irrelevant areas. Kekule (2015) reported the first approaches in this respect, comparing the distribution of visual attention between students with best and worst performance while working on the TUG-K. Overall, although eye tracking was previously used in several studies in which participants were solving problems with graphs, usually only a small number of problems was used and/or a small number of students participated. Student understanding of important concepts related to graphs, such as graph slope and area under a graph, as well as the performance in different contexts were usually not in the focus of these studies. Therefore, we decided to use eye-tracking to investigate students' understanding of the slope of a graph and the area under a graph in different cohorts and in different contexts.

Research Questions

We aimed to answer the following research questions:

1. How do the physics and the non-physics students solve tasks associated with slopes and the area under a graph in the context of physics and in the context of finance?
2. Do the eye movements of the students reveal differences between finance and physics questions with respect to their performance?

Methods

The data analysed in this paper come from two studies conducted by the authors in 2018 and 2019 in Croatia and Germany (Susac et al., 2018; Klein et al., 2019). There are already two publications in which the results of the individual studies are presented separately and here the two data sources are merged. Both studies used identical materials and the same schedule, and subtle differences have already been mentioned in Klein et al. (2019). In particular, no comparison of the performance data was possible in the individual studies, as Susac et al. (2018) had made an adjustment of the score based on written protocols, which Klein et al. dispensed with. For the evaluation here, the raw performance data (i.e. without adjustment to the written statements of the students) were used to allow a direct comparison. Eye-tracking data from different systems were extracted and fed into a common database. In the methods section, the materials, the participants, the procedure, and the analysis methods are described again in order to give a new reader a holistic insight into the study.

Participants

The total data basis consists of 157 students which ranks this study among the larger studies in STEM disciplines using eye-tracking technology. The physics students that participated in the study were from the University of Kaiserslautern ($N = 29$), Germany, and the University of Zagreb ($N = 45$), Croatia. The non-physics students were economics students from the University of Mainz ($N = 40$) and psychology students from the University of Zagreb ($N = 45$).

In Germany, physics is taught as a compulsory subject for 4 years in the lower secondary level (grades 5–10, participant age 11–16). In kinematics the basic quantities (time, distance) are introduced and basic ideas are taught, such as the concept of velocity and acceleration and their (indirect) measurement. The explicit teaching of kinematics graphs begins in the physics courses at the beginning of upper secondary school (participants aged 16–17), where physics is not a compulsory subject. Most physics students (89%) chose the physics course at school, while only a minority of economics students (16%) did so. None of the students were confronted with kinematics graphs after school. Especially the physics students had not learned anything about kinematic graphs in the university courses, because the experiment took place in the first weeks of the students' first year of study. According to the faculty, the economics students did not encounter similar graphs in their finance courses as in this study. Obviously, the business students did not learn about kinematics graphs after school, since kinematics is not part of a business curriculum.

In Croatia, physics is a compulsory subject taught in the last two grades of all primary schools and during the four years of most grammar schools (gymnasia). Students are taught kinematics graphs at the age of 15 and 16 (last class of primary school and first year of grammar school). Psychology students were not confronted with kinematics graphs after high school, while physics students also learned about kinematics graphs in several university courses. Students of physics and psychology had not been exposed to graphs in terms of prices, money, etc. in their formal education. In Croatia the participants were prospective physics teachers whereas in Germany, the students chose the subjects physics and finance as scientific majors.

Materials

Eight multiple-choice test items were developed or modified from a previous study (Planinic et al., 2013). Four sets of isomorphic questions on graphs in the context of physics (kinematics) and finance related to the qualitative and quantitative understanding of the slope and area under a graph. Isomorphic questions required the same mathematical approach to kinematics graphs and graphs related to prices (we will call them finance graphs). The text of the question and the appearance of the graph were similar for the isomorphic test items to allow comparison of the effects of the two contexts, see Fig. 12.1. We prepared two versions of the test, with a balanced sequence of physics and finance questions. The isomorphic questions were never asked one after the other.

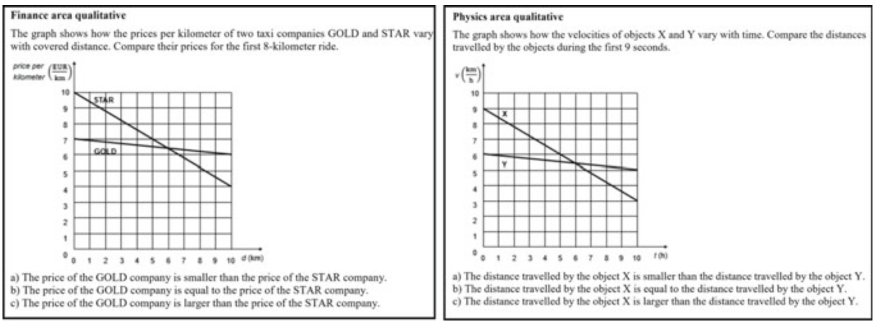


Fig. 12.1 An isomorphic pair of qualitative questions about the area under a curve

Apparatus

In Croatia, eye-movement data were recorded using a stationary eye-tracking system with a temporal resolution of 500 Hz and a spatial resolution of 0.25°–0.50° (SMI iView Hi-Speed system, Senso Motoric Instruments G.m.b.H.). The distance between the eyes and the monitor was 50 cm. In Germany, the eye movements were recorded with a Tobii X3-120 stationary eye-tracking system[1] which had an accuracy of less than 0.40 degree of visual angle (as reported by the manufacturer) and a sampling frequency of 120 Hz. The system allows a relatively high degree of freedom in terms of head movement (no chin rest was used). To detect fixations and saccades, an I-VT algorithm was adopted (Salvucci & Goldberg, 2000). A fixation can be defined as the state when the eye remains still over a period of time, while a saccade is the rapid motion of the eye from one fixation to another. Smaller eye movements that occur during fixations, such as tremors, drifts, and flicks are called microsaccades. Regarding both systems, an eye movement was classified as a saccade (i.e. in motion) if the acceleration of the eyes exceeded 8500 degrees/s2 and velocity exceeded 30 degrees/s.

Procedure

First, the participants were familiarized with the apparatus and the way to answer the questions (by pressing a key on the keyboard, and by choosing the answer using the mouse). The participants were asked to keep their head fixed during the measurements, so they could not use paper and pencil. After calibration, questions were presented to a participant one by one. The eight multiple-choice items were presented in a partially counterbalanced sequence (i.e. isomorphic questions were never presented one after another). Each slide contained the question, the diagram, and the answer options. By choosing the answer, the participant advanced to the next question. There was no time limit to answer the questions. The whole procedure, including preparation, eye-movement calibration and recording, lasted around 20 min.

Results

Students' Scores

Table 12.1 shows the performance data (raw test scores) for the German and Croatian physics students per item type (upper part of the table). With the exception of the qualitative slope questions, the physics students' performance decreases when

[1]More specifications can be found on the product website https://www.tobiipro.com.

Table 12.1 Students' scores for each question

	Slope				Area			
	Qualitative		Quantitative		Qualitative		Quantitative	
	Physics	Finance	Physics	Finance	Physics	Finance	Physics	Finance
Physics students								
German (N = 27)	0.82	0.89	0.74	0.52	0.89	0.59	0.59	0.52
Croatia (N = 45)	0.87	0.84	0.91	0.71	0.80	0.67	0.69	0.44
Non-physics students								
German (N = 40)	0.83	0.83	0.48	0.20	0.55	0.38	0.15	0.28
Croatia (N = 45)	0.82	0.89	0.47	0.29	0.64	0.60	0.07	0.11

changing from the physics to the finance context. This observation is quantified in the following using repeated-measure ANOVAs with context as the main factor (physics vs. finance) and group as the between-subject factor (German vs. Croatian physics students).

For the quantitative slope questions, the analysis yields a significant main effect of the factor context ($F(1, 70) = 11.8, p < 0.001, \eta^2 = 0.15$) and a significant between-subject effect ($F(1, 70) = 4.9$, $p = 0.03$, $\eta^2 = 0.07$). The Croatian students solved the problems better than the German students, and the physics questions were easier than the finance questions. There was no interaction effect. For the qualitative area questions, the same analysis procedure was applied. We found a significant main effect of the factor context ($F(1, 70) = 10.5$, $p = 0.002$, $\eta^2 = 0.13$), without any group or interaction effects. The same holds for the quantitative area questions, i.e. there is a significant main effect of the factor context ($F(1,70) = 5.4, p = 0.02, \eta^2 = 0.07$), without other effects. In both cases, the physics problems were solved better than their isomorphic pairs with finance context. For the qualitative slope questions, there were no significant effects.

For the non-physics students (lower part of Table 12.1), the same analysis procedure was applied. The context of the question had a significant impact on the scores only for the quantitative slope question ($F(1, 83) = 9.6$, $p = 0.002$, $\eta^2 = 0.11$). Similar to the physics students, the non-physics students had more difficulties with the finance question compared to the physics questions.

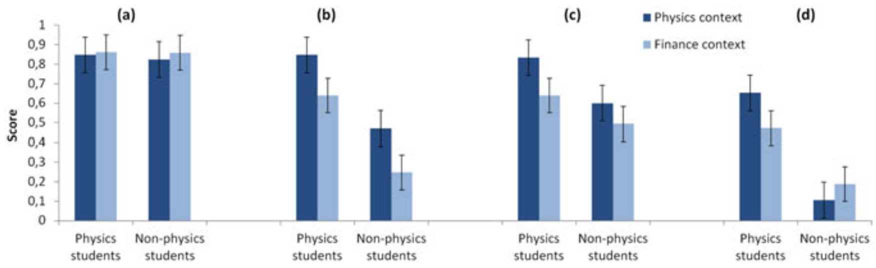


Fig. 12.2 Students' scores for the slope questions (**a** qualitative, **b** quantitative) and for the area questions (**c** qualitative, **d** quantitative). The error bars represent the standard error of the mean

Physics Vs. Non-physics Students

Since only marginal differences between the Croatian and German populations were found, the results were aggregated from the German and Croatian data for each type of question, see Fig. 12.2.

For the qualitative slope questions, a repeated-measure ANOVA with context as the main factor and study domain (physics vs. non-physics) revealed no main or interaction effects. For all other question types, main effects of context were found, which is in line with the results reported above. Additionally, there were significant differences between physics and non-physics students [slope quantitative: $F(1, 155) = 50.0, p < 0.001, \eta^2 = 0.24$; area qualitative: $F(1, 155) = 9.0, p = 0.002, \eta^2 = 0.06$; area quantitative: $F(1, 155) = 56.7, p < 0.001, \eta^2 = 0.27$]. For the quantitative area question, we also found an interaction effect between study domain and context ($F(1, 155) = 11.2, p < 0.001, \eta^2 = 0.07$). That means, physics students solved better the physics questions than the finance questions whereas non-physics students performed better on finance questions compared to physics questions. A post hoc t-test for this question type (area quantitative) revealed that the difference between non-physics students' scores on physics and finance questions is statistically different ($p = 0.03$), and also the difference between physics students' scores on physics and finance questions is statistically different ($p < 0.001$).

Dwell Times

From the eye-tracking data, we extracted total dwell times for each student and each item, see Fig. 12.3.

Regarding population effects, we observe that physics students and non-physics students spent similar time on the graphs; with one exception, that is the qualitative area question. For the qualitative area question, the physics students spent more time on the graphs (physics/finance context) compared to the non-physics students. Regarding context effects, we observe that physics students and non-physics students

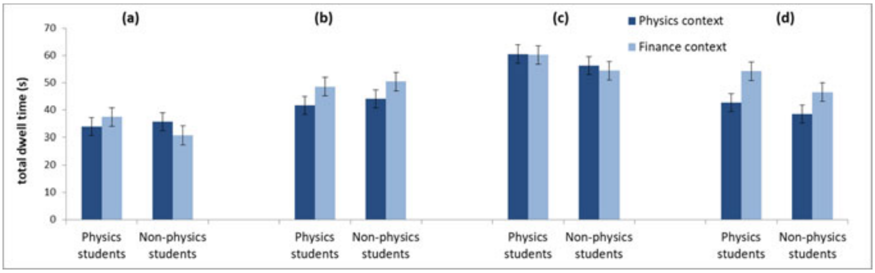


Fig. 12.3 Total dwell times for the slope questions (**a** qualitative, **b** quantitative) and for the area questions (**c** qualitative, **d** quantitative)

spent similar time on the qualitative questions in both physics and finance contexts. However, for the quantitative slope question, the students (both physics and non-physics) spent more time on the finance question than they spent on the physics question ($F(1, 155) = 6.13, p = 0.01, \eta^2 = 0.04$), and the same holds for the quantitative area question ($F(1, 155) = 13.6, p < 0.001, \eta^2 = 0.08$).

Attentional Distribution on Quantitative Area Question

In order to gain a better understanding for the decrease of the physics students' performance when switching from the physics to the finance context, we analyzed the visual attention distribution for one pair of isomorphic items in more detail. We chose the quantitative area question for this purpose because it was the most difficult question for the students, and technically, the graph had exactly identical dimensions in the German and the Croatian study which is crucial for applying the pattern analysis. Figure 12.4 shows the heatmaps for the physics students while solving the physics and finance question.

The heatmaps are presented for the German and Croatian physics students separately since different eye-tracking systems have been used in both studies. The quantitative area question requires to determine the area under the graph between the abscissa values "0" and "8".

Figure 12.5 shows the difference plot of a pattern analysis that was performed to the fixation count data. Data extraction was restricted to the graph region (excluding the question, the alternatives, and axis labels) in order to obtain a measurement of cognitive activity with the graph itself. The figure presents the differences in visual attention between both isomorphic items (physics context vs. finance context). If students spent more time to an AOI when the question was presented with physics context, the AOI is coloured green. Otherwise, e.g. when an AOI received more attention in the finance context, it is coloured red. Uncoloured AOIs reflect areas with no difference in visual attention between physics and finance context, occurring either if there was no visual attention at all or both the students allocated the same number of fixations when solving the items.

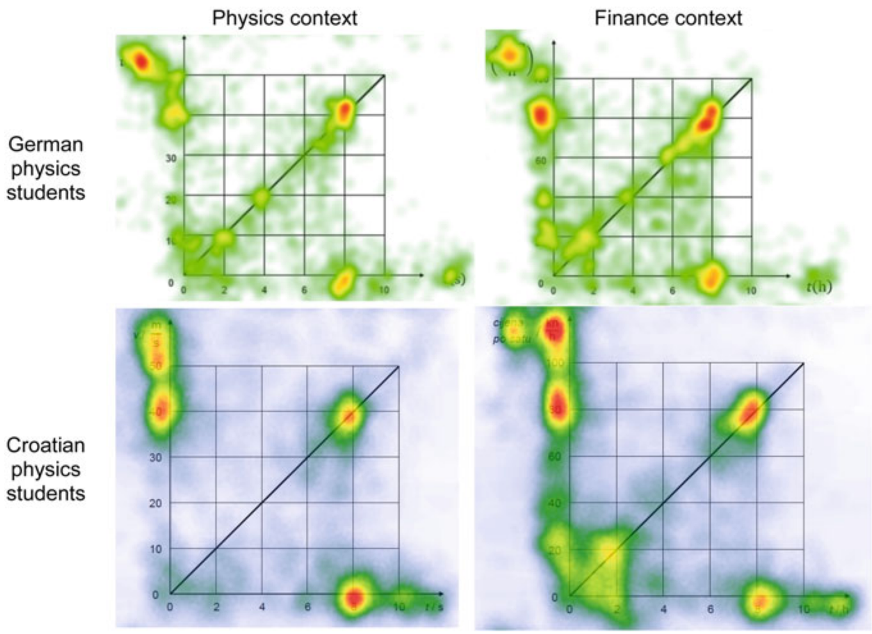
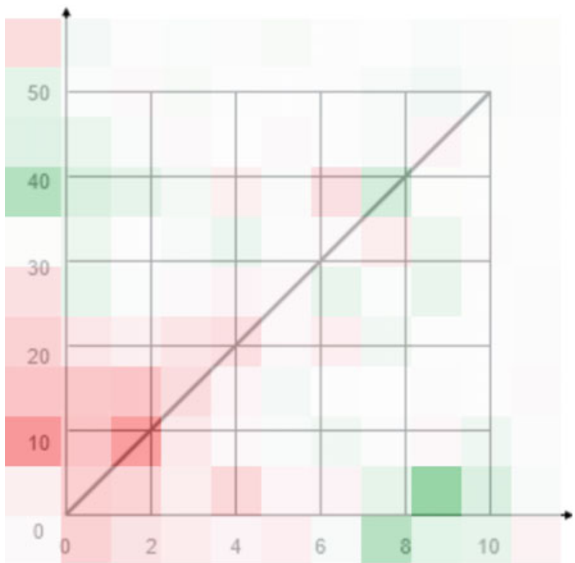


Fig. 12.4 Heatmaps of Germans and Croatian students solving the isomorphic pair of quantitative area tasks

Fig. 12.5 Analysis of visual attention and saccadic eye movements for the isomorphic pair of quantitative area questions (all data). The green (red) colour indicates areas that received more attention when the question was presented with the physics (finance) context



Attentional Distribution of Qualitative Slope Questions

Additionally, we analyzed the distributions of visual attention in the same manner as in as above for the isomorphic pair of qualitative slope items. According to Table 12.1 and Fig. 12.2a, most of the students solved this task successfully, indicating that they either transferred the mathematical procedures (slope concept) between both domains or had an intuitive idea about slope (meaning steepness) in both domains.

Figure 12.6 shows the attentional distribution of the Croatian and German physics students while solving the isomorphic pair of qualitative slope questions. The item pairs were not 100% isomorphic on the surface level, i.e. students were asked to compare the slopes of both graphs at the abscissa "3" for the physics question and at the abscissa "5" for the finance question, respectively. However, the mathematical procedure, the scaling of the axes, the location of the graphs, and their shapes were identical.

Due to the small difference between the framing of the question, i.e. comparing the slopes at different abscissa values, we cannot apply a pattern analysis that highlights the difference between both isomorphic questions conveniently as we did for the quantitative area question.

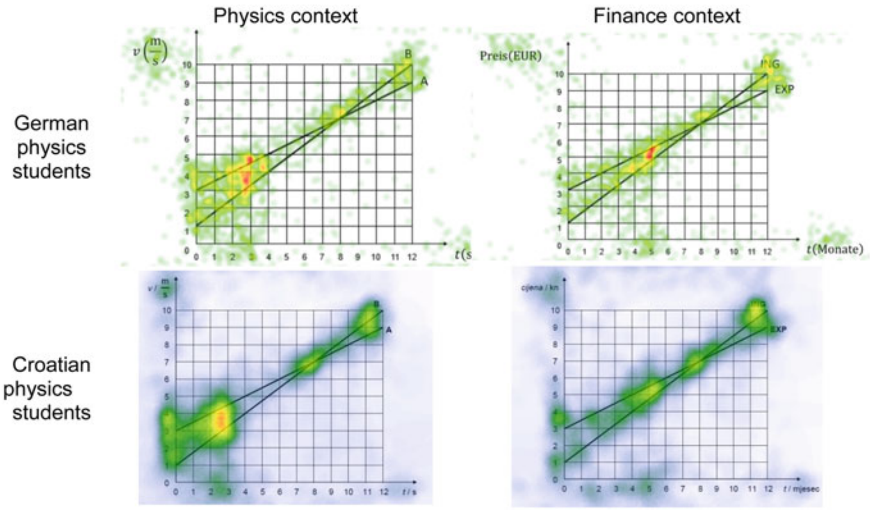


Fig. 12.6 Heatmaps of German and Croatian physics students while solving the isomorphic pair of qualitative slope questions. Note that students were asked to compare the slopes of both graphs at the abscissa "3" for the physics question and at the abscissa "5" for the finance question, respectively

Discussion

Discussion of Scores

A. Physics students achieved higher scores than non-physics students

Physics students performed significantly better overall than non-physics students. Apart from the qualitative questions about the slope of the graph, physics students had significantly higher scores in all combinations of question type and concept. This is true for the first-year physics students from Germany and the prospective fourth-year physics teacher students from Croatia. The combination of data from both studies also showed that psychology students and economics students both scored worse than the physics students, and both samples of non-physics students are comparable in terms of performance. This conclusion could not be drawn from the original data presented in Klein et al. (2019) and Susac et al. (2018) because the raw test results were not reported.

B. The slope of the graph seems to be a simpler concept for physics and non-physics students than the area under a graph

All students solved the questions about the slope of the graph better than the questions about the area under a graph. In particular, the qualitative questions about the slope of the graph were correctly solved by about 80% of the students in both contexts, which suggests that this idea is intuitive for physics and economics students (e.g. in connection with consumer or producer surplus). The non-physics students also had no difficulty with the qualitative question of the slope of the graphs in the physics context. This suggests that both the economics and psychology students were able to identify acceleration as a slope in velocity-time graph and growth rate of prices as a slope in the price-time graph.

C. Quantitative questions are more difficult than qualitative questions for first-year physics students

For the quantitative slope question, the analysis showed a significant main effect of the group factor, revealing that the Croatian physics students solved the questions better than the German physics students. In other words, the first-year students had more difficulties with the quantitative problems than with the qualitative ones, while the fourth-year students examined by Susac et al. solved both types of problems equally well. Similar results of this kind have been reported earlier for freshmen (Planinic et al., 2013), so the difference between the results is probably due to the differences between the two physics samples. As Susac et al (2018) emphasize, "studying physics improves [students'] ability to solve quantitative problems on graphs".

D. Physics students solved finance question better than non-physics students that indicates transfer

Physics students solved the physics questions better than the finance questions which is not surprising considering that they chose physics as their field of study. They also solved the finance questions very well and even better than the economics students. Since physics students have probably never been confronted with this kind of questions before, our results show that physics students seemed to be able to successfully transfer the mathematical strategies they developed at school in physics or mathematics to solve problems in a different context.

Discussion of Students' Visual Attention Using Dwell Time Analysis

The aggregated data set shows that both groups of students (physicists and non-physicists) spend more time on questions about the area under the graph than on questions about the graph slope. This proves that the area concept is more difficult for students than the slope concept, as longer viewing times are associated with a higher cognitive effort (Gegenfurtner et al., 2011). Furthermore, it was confirmed that solving quantitative questions about graph slope is more time-consuming than solving the qualitative question. Longer viewing times for quantitative questions on graph slope are usually due to longer viewing times of the axis tickets (Klein et al., 2019), which supports the idea that information extraction and processing contributes to the difference, and extends the previous results: Susac et al. (2018) explain the different viewing times by the fact that students have to extract more information from the graph when they have to make calculations.

The qualitative assessment of the area below the graph required the longest time across all items. It took even longer than the quantitative calculation of the area under the graph, which is an opposite trend of the viewing times when comparing the qualitative and quantitative questions of the slope. The result again agrees well with the literature and can be explained by the fact that, first, the area under a graph is not estimated as fast as the slope of the graph and second, these types of questions were likely to be new for both groups of students so maybe they needed more time to evaluate what to look for and where.

Analysis of Visual Attention Distribution on the Graphs: Success and Failure of Transfer

For the quantitative area question, the physics students solved the physics problem better than the finance problem. Since the graph in that question is linear and crosses the origin (compare Fig. 12.4), the area under the graph corresponds to a triangle and one possible correct solution strategy consists of the following steps

1. extracting the height of the graph at the abscissa "8"
2. multiplication of "8" and the height of the graph
3. division by 2.

Therefore, the relevant points of interest are the value "8" on the abscissa, the graph height, and the corresponding ordinate value. Additionally, students have to recognize that the graph passes the origin and that the graph is a straight line. As can be seen from Fig. 12.4, these points attract much attention in the physics context, especially for the Croatian students who solved this task correctly in 69% of cases (cf. Table 12.1). In the finance context, the Croatian physics students allocate more attention around the origin and the point (2/20); the performance drops to 44%. The heatmaps of the German students are similar, yet the difference and the drop of performance (59% --> 52%) are less pronounced. As can be seen, the units on the axis are also important areas of interest because they helped students to understand that they need to determine the area. In previous analyses it was shown that physics students spent more time on the finance axis, i.e. they needed more time to extract information from the axes in graphs with the context that was unfamiliar to them (Klein et al., 2019; Susac et al., 2018). The pattern analysis, i.e. the direct comparison of visual attention on the isomorphic pairs of question (Fig. 12.5), revealed that physics students allocate more attention to relevant regions when the question is posed in the physics context. They spent more time viewing the area around the origin in the finance version of the question and also spent more time viewing the y-axis values and x-axis values below that are smaller than the relevant numbers. It is possible that students were confused which procedure they had to apply for solving the question. Susac et al. (2018) reported that some calculated the slope instead of the area and the attention to smaller numbers possibly comes from this confusion. So possibly, some students tried to calculate the slope and when they saw it was not offered as the answer, they tried another strategy. Few students developed (incorrect) strategy to sum y-axis values for each of the eight hours. From the original protocol data of Susac et al. (2018), we found some examples that explained this issue. One student's explanation was "For the first hour he earns 10 kn, the second 20, the third 30, etc. So, for 8 h he earns $10 + 20 + 30 + 40 + 50 + 60 + 70 + 80 = 360$ (which I did wrong: on summation I got result 320)". Another student calculated the area by counting squares ("A total of 8 squares below the line, the area of each is 40 kn, in total earns 320."). The higher dwell times on the finance questions is also an indicator of unconfidence (Klein et al., 2019). When physics students encountered graphs in new context (finance) they spent some time to develop a strategy, i.e. to understand what they were supposed to do. For example, in quantitative questions about area under a graph, they had about 10 s longer total dwell time for finance question than for physics question (Fig. 12.3). The majority of physics students knew as a fact that covered distance corresponded to the area under the v vs t graph, so they calculated the area under a graph, or they used physics formulas. In the finance question, they could not rely on learned facts or formulas from physics, so they had to invent new strategies or modify the strategies learned in physics. Figure 12.4 indicates that physics students spent more time attending parts of the graph that are not relevant for the easiest solution (i.e. calculation of the area of triangle) in finance context than in physics context.

For the qualitative slope question, the transfer seemed to be achieved successfully. From Fig. 12.6, one can clearly observe similarities between the German and the Croatian physics students concerning both items (vertical comparison of the figures). The student allocated their attention at the lower part of the diagram ("$x = 3$" for the physics question, "$x = 5$" for the finance question), the affiliated y-labels on the ordinate, the intersection between the graphs, and at the axis and graph labels. When comparing both pair of items (physics and finance questions), the areas listed before received similar attention (horizontal comparison of the graphs). The qualitative slope question was also the easiest question for all students, indicating a moderating role of question difficulty on transfer abilities. A working hypothesis for upcoming work thus reads that students have more trouble to transfer mathematical procedures to unfamiliar domains if they have troubles to solve the initial question in their familiar domain. In other words, the "context gap" increases for difficult items.

Conclusion

The aim of this study was to compare physics and non-physics students regarding their understanding of graph slope and the area under the graph in the contexts of physics and finance. In doing so, two data sets from German and Croatian students have been aggregated. The thorough eye-tracking analysis sheds more light on differences when changing the context in a question using isomorphic pairs. The analysis of visual attention shows that in cases of apparent successful transfer, the main focus was on features that were relevant for solving the problem. When transfer seemed to fail, students directed their attention from relevant to irrelevant regions of the graph. This pattern suggests that transfer competence could potentially be supported by visual highlights, guiding the students' attention toward relevant areas.

Apart from that, our results broadly confirm previous findings on student understanding of graphs, i.e. graph slope is an easier concept than the area under the graph for physics and non-physics students. Area questions required more time and were therefore cognitively more demanding, indicating that more emphasis should be put on the qualitative and quantitative evaluation of the area concept. Overall, our results highlight the importance of an instructional adjustment toward more emphasis in education on graph interpretation.

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