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LOWER-SECONDARY STUDENTS' UNDERSTANDING OF CONSTANT VELOCITY MOTION GRAPHS

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Abstract. *In science, one of the most crucial representations for constructing meaning about physical events is graphs. The first graph students encounter in science class is the constant velocity motion graph. Therefore, examining students' understanding of structuring and interpreting these graphs for the relationship between distance, time, and velocity may provide significant clues for their future understanding of more complex motion graphs. The constant velocity motion graph interpretation and structuring understanding of 6th-grade secondary school students were explored. It was conducted with 97 students from a small-scale province in the east of Türkiye. The data were collected using the "Form on Interpretation and Construction Skills of Constant Velocity Motion Graphs." The data were analyzed using descriptive analysis. It was found that the students mostly used irrelevant reasoning and symbolic reasoning, and the least multiple variable reasoning for graph interpretation. In addition, it was determined that students used irrelevant reasoning the most and single variable reasoning the least in all questions prepared for graph structuring. These results suggest that many students find it difficult to understand complex motion graph questions in the future.*
Keywords: *constant velocity motion graph, graphic literacy, students understanding, qualitative analysis*

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Introduction

Graphical interpretation and structuring in science education enable students to compare and make connections between facts by visualizing numerical data or digitizing visual information. Skills in interpreting and structuring graphs include flexibly and creatively using graphical representations that students may not have encountered before, critically evaluate them, and applying their understanding to solve various problems (Duijzer et al., 2019). The background knowledge students have in mathematics and physics is vital to their science performance and affects their ability to interpret graphs (Hazari et al., 2007; Phage et al., 2017; Shah & Freedman, 2011). Graphic comprehension encompasses the processes of reading, interpreting, analyzing, and integrating information presented in various visual forms (Patahuddin & Lowrie, 2019). To effectively analyze graphs, students must first recognize and categorize vital visual elements, such as the structure of the curve or the aggregation of data points. Subsequently, they must interpret these characteristics by evaluating the intensity of the associations among the variables (Lai et al., 2016). Additionally, reasoning with graphical representations requires students to identify interrelationships between the variables on the (x) and (y) axes, as well as to compare elements within individual graphs and across multiple graphs (Duijzer et al., 2019). Graphs are particularly significant in subjects related to force and motion, especially in the domain of kinematics. Graphic literacy is crucial in scientific contexts because it helps to reduce cognitive load, highlight links between visual components and real-world occurrences, and facilitate scientific reasoning (Shah & Hoeffner, 2002). Lakoff and Núñez (2000) have argued that graphs are connected to embodied images of imagined movements and source–path–goal schemas. These schemas enable students to translate real-world experiences, such as moving through space, into mathematical representations (Duijzer et al., 2019).

A lack of solid understanding of graphs representing real-world motion can make it even more challenging for students to grasp concepts such as velocity and functions in kinematics (Glazer, 2011). As kinematic phenomena

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grow more complex, the demands on visual and spatial processing are likely to increase (Kozhevnikov & Thornton, 2006). Kinematic graphs are mathematical-physical models used in most cases to represent the motion of objects, assuming constant acceleration. These models arise from the integration of theoretical physical understanding with the foundational and technical principles of mathematics, enabling the mathematical representation of a physical system or process (Phage et al., 2017; Redish & Kuo, 2015; Uhden et al., 2012). The process of creating and interpreting motion graphs can vary greatly, ranging from large or small body movements to simply observing the motion of an object or individual (Duijzer et al., 2019). Graphing entails representing the relationships within data sets, experiments, or scientific phenomena (DiSessa et al., 1991; Lai et al., 2016). This process necessitates that students not only analyze the components of graphs but also apply these components when constructing their graphs (Lai et al., 2016).

In Türkiye, questions requiring the interpretation of graphs as mathematical representations of specific motion situations are commonly included in both the high school transition exam and the university entrance exam in the field of natural sciences. Such graph interpretation is also increasingly featured in international assessments like PISA and TIMSS. Interpreting real-world graphs requires drawing appropriate conclusions and addressing contextual problems (Freedman & Shah, 2002; Phage et al., 2017). Graph comprehension is a multifaceted process both encompassing basic perceptual tasks, such as locating a point, and more advanced activities that necessitate drawing multiple inferences (Lai et al., 2016).

Lower-secondary students begin learning to interpret and construct graphs with the topic of constant velocity motion in science. As such, it is crucial for students to make accurate inferences about the mathematical relationships and comparisons of physical events early on, as this will help them understand more advanced kinematic graph concepts in the future and comprehend the link between physics and mathematics. The link between a physical experience and its graphical depiction illustrates embodied cognition (Duijzer et al., 2019). One of the defining characteristics of physics is the mathematical definition of physical processes (Uhden et al., 2012). Many students find solving physics problems challenging because these problems often require visualizing complex spatial processes and mentally structuring graphs (Kozhevnikov et al., 2002). Some scholars suggest that students' challenges in interpreting graphs in science arise from gaps in their mathematical knowledge rather than difficulties in transferring mathematical concepts to scientific contexts (Phage et al., 2017; Potgieter et al., 2008). Graphical literacy is considered a higher-order cognitive skill, essential for individuals who are scientifically literate and capable of understanding and interpreting various visual representations in today's society (Boote, 2014; Patahuddin & Lowrie, 2019). When students are able to read a graph, comprehend its meaning, and draw insightful conclusions from it, this demonstrates their understanding of the graph (Glazer, 2011; Phage et al., 2017). Clearly, the ability to create and interpret graphs is crucial for both understanding and conveying scientific information (Berg & Smith, 1994).

Research on lower-secondary students' comprehension of motion graphs has been scarce. Some of these studies highlight the influence of technology-enhanced applications on lower-secondary students' comprehension of motion graphs (Anderson & Wall, 2016; Deniz & Dulger, 2012; Ferrara, 2014). Beyond these studies, only a few research efforts in the past twenty years have concentrated on lower-secondary students' skills in understanding, analyzing, and creating motion graphs (Duijzer et al., 2019; Lai et al., 2016). Many successful countries in science education, particularly the United States, emphasize that understanding, interpreting, and constructing graphs during lower-secondary are essential skills in the 21st century. Unfortunately, there is a widespread lack of relevant literature concerning the cognitive difficulties of lower-secondary students in constructing and interpreting kinematic graphs. In Türkiye, so far, there hasn't been a study that reveals the understanding of lower-secondary students about constant velocity motion graphs, which is one of the fundamental kinematic topics in their early years. Therefore, it is essential to determinate the understanding of lower-secondary students in Türkiye about interpreting and constructing kinematic (constant velocity motion) graphs, which is a crucial tool for promoting 21st-century skills in the field of science. This study expands the research literature on kinematic graphs through a descriptive study. It also provides valuable information for teacher training and curriculum improvement efforts in Türkiye.

The Graph Representation in Science Education

Graphics play a fundamental role in higher-order thinking processes in math and science education (Boote, 2014). Graphs are among the most widely used mathematical tools for visualizing information (Lowrie et al., 2007; Lowrie et al., 2012). In scientific contexts, graphical literacy encompasses the capacity to identify and articulate the features of graphs, align them with other forms of representation that convey similar data (such as tables), and

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interpret them within a scientific framework (Lai et al., 2016). The way information is represented significantly influences students' comprehension of concepts and their ability to interpret different mathematical situations (Lowrie et al., 2007). McKenzie and Padilla (1984) proposed that students' ability to draw graphs has been connected to their understanding of scientific relationships (Berg & Smith, 1994). Students must grasp the characteristics of graphs in order to recognize, explain, and assess claims related to scientific phenomena (Zucker et al., 2014). Graphical representations are frequently employed in data analysis to identify trends and associations among variables, as well as to visually present results (Shaughnessy et al., 1996). Unlike tables of numbers or textual descriptions, graphs condense large volumes of information into a more concise and accessible format. Furthermore, graphs can visually and spatially depict continuous changes and common variability in ways that tables are unable to represent (Zucker et al., 2014). Shah and Hoeffner (2002) have conceptualized graphical literacy through three components: encoding visual information, connecting visual elements to the concepts they represent, and interpreting the disciplinary context (Lai et al., 2016). In the same way, a solid grasp of science graphs can support the acquisition of novel scientific principles. From this angle, the link between graph comprehension and scientific concepts is both interactive and influenced by context (Lai et al., 2016).

Students' ability to comprehend graphs is crucial in all scientific fields, particularly in physics and mathematics (Ivanjek et al., 2016). In science education, graphs serve as a link between real-world contexts (such as scientific experiments) and the interactions among the variables present in those contexts (Zucker et al., 2014). In physics, data is typically gathered from real-life scenarios, and graphs must be defined, represented, analyzed, and interpreted within the appropriate contextual framework (Phage et al., 2017). The ability to reason with the information presented by a graph is a complex skill. Studies show that students often struggle with reasoning about graphs, especially in relation to subject-specific concepts within scientific fields (Rodriguez et al., 2018). These challenges highlight students' difficulties in connecting the features of a graph to particular physics concepts (Phage et al., 2017). Students, for example, may need help extracting kinematic values from graphs, relating different types of kinematic graphs to one another, and interpreting graphs correctly (Christensen & Thompson, 2012). A common issue is that students misinterpret graphs as direct representations of motion. Those who face challenges in this area might, for instance, mistakenly read a velocity-time (v-t) graph as depicting motion along a curved path. These students have not yet developed the understanding that the graph is an abstract symbolic representation of the relationship between the variables on the axes; instead, they interpret it as a direct visual depiction of an object's motion. As a result, they struggle to understand why the graph changes when the variables on the axes are altered, often expecting the graph to remain unchanged (Ivanjek et al., 2016). Specific issues include students' prior knowledge, developmental stage, individual characteristics, the features of the graph, estimation tasks, and the challenges of interpreting graphs either literally or symbolically (Boote, 2014).

Graphical representations are commonly employed in scientific texts to communicate quantitative data, but students often face challenges understanding and grasping the associated material. Cognitive research on graph interpretation indicates that it involves (a) relatively straightforward perceptual and associative processes, where students correlate graph patterns with quantitative values, and (b) more intricate, error-prone inferential processes, where students are required to manipulate the data mentally (Shah et al., 1999). In the study of kinematics, data is commonly presented using three primary types of graphs: position-time (r-t), velocity-time (v-t), and acceleration-time (a-t). These three graphs serve to illustrate how an object's motion evolves over time, providing insight into the object's state of movement (Volkwyn et al., 2020). To interpret a graph, a student must understand this information, which requires recognizing the features and context of the graph and being able to draw valid conclusions from it (Lai et al., 2016; Roth & Bowen, 2001). Since motion graphs are challenging to interpret, many students' understanding of graphs is fragile. There is a need for improved teaching strategies, curriculum materials, and instructional tools to support students in developing a deeper understanding of graphs and effectively using them (Zucker et al., 2014). Science educators often find it challenging to teach the graphical concepts needed in science, which results in students having trouble constructing and interpreting graphs (Galesic & Garcia-Retamero, 2011; Jarman et al., 2012; Lai et al., 2016).

Related Studies

A limited number of studies have examined students' comprehension of motion graphs. Among these, the study by Duijzer et al. (2019), which serves as a key reference for this research, stands out as one of the most influential in recent years. Duijzer et al. (2019) explored how primary school students (ages 9-11) can be supported in developing their abilities to interpret and structure motion graphs. The study specifically examined the effectiveness

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of a six-hour hands-on learning environment in fostering students' understanding of motion graphs. In this study, students used motion sensor software to create position-time graphs. As part of the process, students moved in front of a motion sensor, producing distance-time graphs based on their movements. The aim was for students to model and graph their own motion using the sensors, encouraging them to connect graphical representations with their personal physical experiences. The results showed that students progressed from a symbolic conception of motion to one in which they applied reasoning based on one or two variables when interpreting and creating motion graphs.

Anderson and Wall (2016) examined the potential of using Kinect technology as a pedagogical tool to improve lower-secondary students' understanding of fundamental kinematics concepts in science classrooms. Specifically, they explored how integrating Kinect with virtual graphics software could affect students' comprehension of displacement, velocity, and acceleration. The study's results indicated that this technological integration could be an effective tool to support students' learning of kinematics. In their review, Duijzer et al. (2019) examined embodied learning environments designed to assist students in comprehending graphs in the context of motion modeling. This study aimed to enhance the theoretical understanding of which instructional and learning environments are most effective in helping students grasp motion graphs. To achieve this, 44 articles from the relevant literature were analyzed. Their findings indicated that several factors, including real-world context, motion graphing, multiple representations, student autonomy, engaging content, and cognitive conflict, all played crucial roles in improving students' comprehension of motion graphs. Additionally, the study highlighted that the most effective learning environments were those that allowed students to directly connect their physical movements with the corresponding graphical representations. Espinoza (2015) explored the kinesthetic impact of utilizing a motion detector with a computer interface to help students interpret motion graphs by focusing on two phenomena: describing a person's movement through sensor-collected data and analyzing the motion of two pendulums-one real and one virtual. The results demonstrated that characteristics related to the movements of the subject and real objects were both statistically and cognitively significant in enhancing students' ability to analyze graphical representations of motion. Zucker et al. (2014) carried out an experimental study to determinate the effects of SmartGraphs software, which was developed to assist students in correcting misconceptions related to graphs. This two-year study, which involved numerous teachers and thousands of students, found that students whose teachers used SmartGraphs in addition to traditional teaching methods had a deeper understanding of motion graphs compared to students who learned the same material from the identical set of textbooks but without the use of SmartGraphs software. Deniz and Dulger (2012) researched the impact of inquiry-based teaching, facilitated by real-time graphics technology, on fourth-grade students' skills in interpreting motion graphs. The findings revealed that the integration of real-time graphics technology notably enhanced the students' ability to understand and analyze motion graphs.

Purpose and Research Questions

This study aimed to assess the understanding of constant velocity motion graphs among 6th-grade secondary school students. In this regard, the research questions that guided the study were:

(RQ1) What is the understanding of 6th-grade students interpreting constant-velocity motion graphs?
(RQ2) What is the understanding of 6th-grade students in structuring constant-velocity motion graphs?

Research Methodology

Research Design

This study utilized a descriptive research methodology. Descriptive research aims to present an existing condition or situation as it is (Creswell, 2014). These studies aim to identify individuals, events, or conditions by observing them in their natural context (Houser, 2008). In descriptive research, the primary focus is on outlining the characteristics of a specific segment without delving into the reasons behind the occurrence of a particular phenomenon. In other words, it "describes" the research topic but does not address the underlying causes (Bhat, 2023). Additionally, in descriptive studies, the researcher does not manipulate any variables (Siedlecki, 2020). Therefore, the descriptive research design was used to assess the knowledge of 6th-grade secondary school students regarding constant velocity motion.

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Participants

The researchers determined that sixth grade students from four lower-secondary with the same socio-economic status in the center of a small province in northeastern Türkiye were eligible for this study. The selected schools represented a moderate level of academic achievement within the province. Moreover, when the science achievement scores of the students in these schools for the previous year and the written exam results up to the time of the study were analyzed, it was seen that the majority of them were concentrated at the middle level. However, it was determined that three of these schools could not participate in the study due to a project being carried out in the province at the time of the study. In this context, it was decided to conduct this study with the 6th grade students in the remaining school. A total of ninety-seven 6th grade students in four different classes at this school participated in this study. The study was conducted in accordance with ethical rules and approved by both the Social Sciences Ethics Committee of the University and the Provincial Directorate of National Education. Consent was obtained from both students and their parents for voluntary participation. In terms of gender distribution, 52 of the students participating in the study were female and 45 were male. The science classes in the classes where the students participated in the study were taught by a teacher with about ten years of professional experience.

Data Collection

In this study, a two-part form consisting of 20 open-ended questions was used to examine students' understanding of graph construction and interpretation in constant velocity. In the first 10 questions of the form, students were asked to interpret constant velocity motion graphs, and in the next 10 questions, students were asked to draw graphs. Examples of graph interpretation and graph drawing questions in this form are shown in Figure 1. The complete form is also included in the appendix.

Figure 1
Constant Velocity Graph Interpretation and Drawing Question Examples

The distance-time graph of the X, Y, and Z vehicles is given below. Accordingly, what can we say about the speed of the vehicles? Explain. (Graphic Interpretation/Question 8)

The school bus, which departs at a constant speed at 09:00, picks up Tuğra at 09:10, Elis at 09:20 and Arya at 09:30. Since there is 300 m between stops, draw the distance-time graph of the schoolbus? (Constructing (Drawing) graph/Question 18)

The sample graph interpretation question given on the subject of constant velocity asks students to interpret the velocities of these vehicles by examining the graph in which the values of the distance taken by three different vehicles at certain time intervals are given. This question measures whether students can correctly interpret the velocity of the three vehicles based on the relationship between the distances they take at different time intervals. The graph constructing (drawing) question, on the other hand, states that a vehicle picks up the passengers waiting at three different stops at 10-minute intervals and that there is a distance of 300 meters between the stops, and asks the students to configure the vehicle's distance-time graph based on this data. This question assesses students' ability to accurately represent the connection between the distance and time variables on the axes (where the x-axis represents time and the y-axis represents distance) for a vehicle moving at a constant velocity, using a single line originating from the graph's origin. To interpret and draw graphs in the form, students need to perform various mathematical calculations. The questions in the form were prepared based on the constant velocity questions in secondary school textbooks, supplementary course resources, and exercise books in Türkiye. In this regard, a pool of 50 questions was first created. Afterward, researchers met with a physics education expert and

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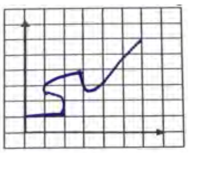
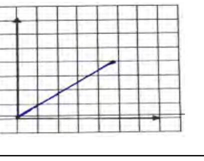
two science teachers responsible for 6th-grade science classes at the school where the research was carried out, to select questions from the question pool for the study and ensure structural validity and reliability.

Researchers discussed the structural aspects of the questions by meeting several times with both physics teachers and science teachers. Within the scope of these discussions, experts, a physics teacher, and two science teachers, identified the issues that they considered would cause misunderstanding of the questions and suggested corrections. In addition, experts have identified inappropriate elements for the scientific structure behind these questions. At the last meeting, 20 questions were selected for this study, the content of which was verified and agreed upon by researchers and experts. The selected questions were formed in a pilot study with 42 students who were in the 6th grade but did not participate in the main study. During this pilot study, the researchers asked the students to write the unclear points about the questions in the spaces on the edges of the questions. The feedback from the students was shown to the experts, experts made various suggestions for rearranging the confusing expressions and improving the graphic images. In this regard, some revisions have been made to the questions for both textual and graphical issues based on student feedback. In addition, the data obtained from this pilot study were calculated statistically. The reliability coefficient of the data collection tool was calculated in SPSS 18 by giving 1 point for correct answers and 0 points for incorrect answers to the questions in the draft form applied to the students for the pilot study. As a result of these calculations, the reliability coefficient of the form was found to be .82. After these stages, the researchers decided that the form, consisting of 20 questions, was ready for actual implementation.

Data Analysis

The data were evaluated using the descriptive analysis method. The data obtained from the constant velocity graphs form were evaluated using the graph interpretation and construction chart of Duijzer et al. (2019) and the reasoning levels of the students were revealed. The responses were evaluated according to a four-fold categorization as "irrelevant reasoning", "Iconic (symbolic) reasoning", "Single variable reasoning", and "Multiple variable reasoning" (Duijzer et al., 2019). The characteristics of this categorization system are given in Table 1. First, the number of students' reasoning levels related to graphic interpretation and structuring was determined separately for each question. Then, the mean percentage of the students' reasoning levels was calculated, taking into account all the questions representing the understanding of graph interpretation and structuring. Two researchers scored 20% of the students' answers for each question. An average consensus of 86% was achieved between the two researchers' codings. After this stage, one of the coders analyzed the rest of the data. Coding differences that arose in some students' responses to interpreting or structuring the graph were resolved by discussing. The results obtained from the data analysis were summarized and interpreted in the form of graphs.

Table 1
Students' Level of Reasoning in Graphic Interpretation and Structuring Coding Schemes

Level of reasoning	Graphic Understanding		
	Interpretation	Structuring	Drawing
Irrelevant reasoning	Without considering the graphical depiction or the motion event itself, it remains a conjecture.	Without taking into account the definition or explanation of the motion event	
Iconic reasoning	Based on the form of the graphical representation or the surface features of the motion event	Based on the superficial features of the depiction of the motion event	

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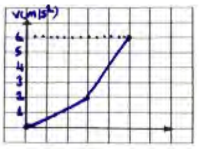
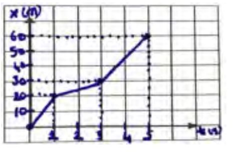
Level of reasoning	Graphic Understanding		
	Interpretation	Structuring	Drawing
Single variable reasoning	Based on a single variable (Distance or time or velocity)	Taking into consideration a single variable	
Multiple variable reasoning	Based on multiple variables (Distance and/or time and/or velocity)	Considering various variables (such as distance, time, and/or velocity)	

Research Results

The analysis results regarding 6th grade students' understanding of interpreting and structuring (drawing) constant velocity motion graphs were listed below, respectively. The students' answers to 20 questions on constant velocity motion were analyzed according to their level of reasoning in graphic interpretation and structuring. The frequency and percentage data indicating the students' reasoning levels for graphic interpretation are shown in Figure 2, and the frequency and percentage data indicating the reasoning levels for graphic structuring are shown in Figure 3.

Figure 2
Frequency and Mean Percentage Values for Students' Graph Interpretation Levels

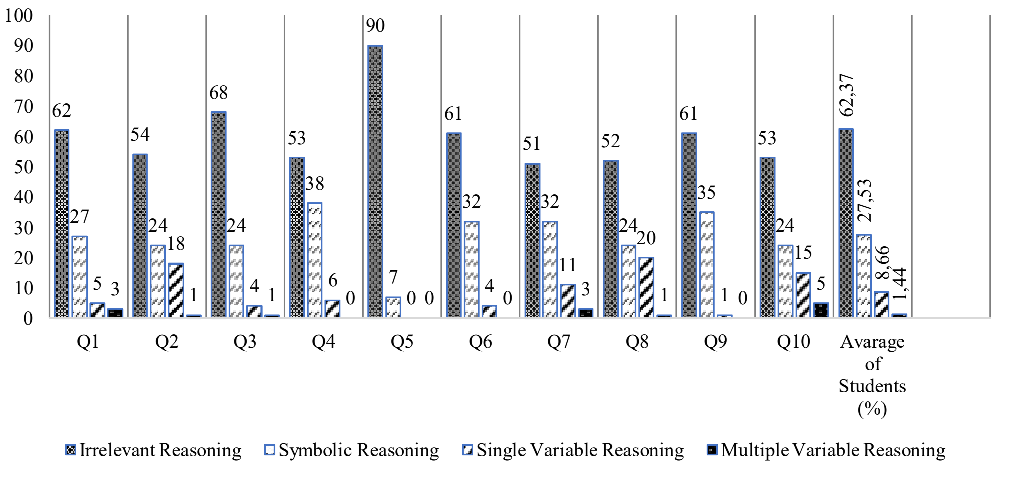


Figure 2 shows that in all 10 questions related to graph interpretation, students mostly used irrelevant reasoning, followed by symbolic reasoning, and at least multivariate reasoning. In addition, it was determined that no student used multivariate reasoning in questions 4, 5, 6 and 9. In addition, it came to the forefront that students did not use univariate reasoning only in question 5. It was observed that students used irrelevant reasoning the most in question 5 and symbolic reasoning the least in question 5. It was determined that students used univariate reasoning most in questions 2, 8 and 10, and least in questions 5 and 9. The results revealed that 62.37% of the students used irrelevant reasoning, 27.53% used symbolic reasoning, 8.66% used univariate reasoning and only 1.44% used multivariate reasoning. These results show that most of the students who participated in the study had significant difficulties in interpreting motion graphs at constant speed. Sample quotations showing the reasoning levels used by the students in the graph interpretation questions are presented in Table 2.

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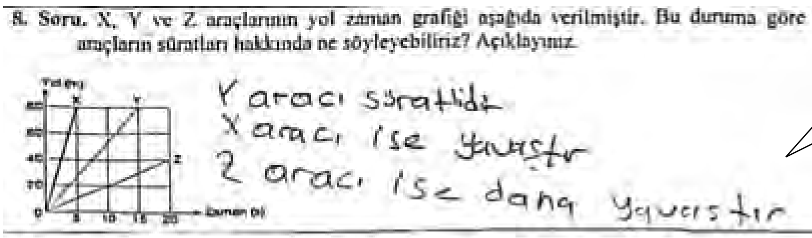
Table 2

Sample Quotations of The Levels of Reasoning Used By Students in Graph Interpretation Questions

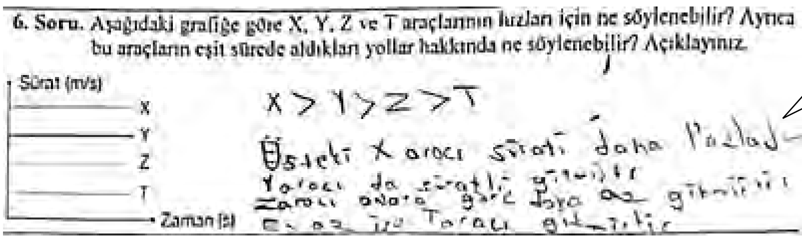
Irrelevant Reasoning



Student answer:
Vehicle Y is fast.
Vehicle X is slow.
Z Vehicle is slower.

The response of Student 4 to Q8.

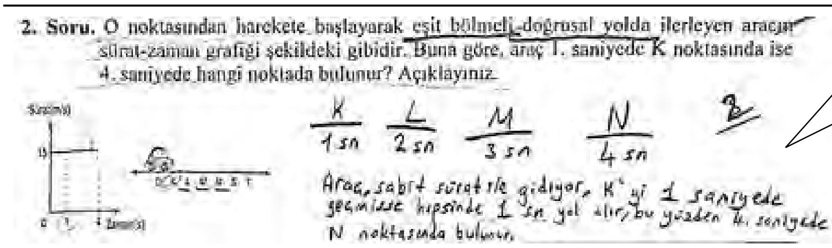
Symbolic Reasoning



Student answer:
X>Y>Z>T
The top X vehicle velocity is higher.
Vehicle Y also went fast.
Vehicle Z traveled less than them.
At least the T vehicle is gone

The response of Student 41 to Q6.

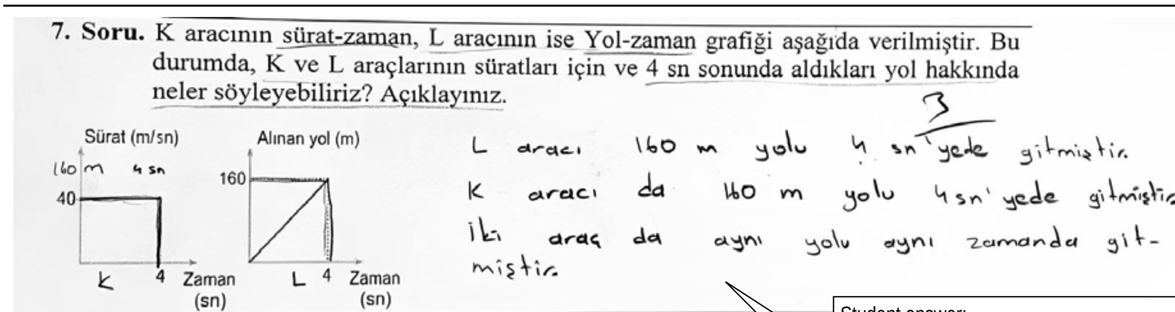
Single Variable Reasoning



Student answer:
The vehicle is traveling at constant velocity. If it passes K in 1 second, they all travel 1 second. Therefore, be at point N in the 4 th second.

The response of Student 21 to Q2.

Multiple Variable Reasoning



Student answer:
Vehicle L traveled 160 m in 4 seconds.
Vehicle K traveled 160 m in 4 seconds.
Both vehicles traveled the same route at the same time.

The response of Student 66 to Q7

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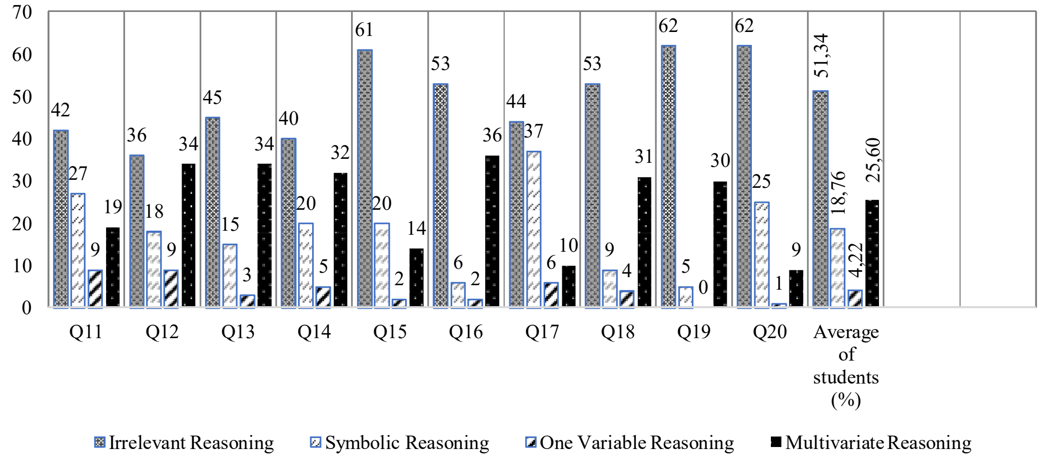
When the student quotations presented in Table 2 regarding the solution of the graphic interpretation questions were examined, it was determined that in solving Question 8, the student made predictions without referring to the graph and values provided in the question. When the student's quotation for the level of symbolic reasoning was examined, it was determined that in solving Question 6, the student made a solution by taking into account the shape and superficial features of the graph provided in the question. When the student's quotation for the level of single variable reasoning was examined, it was determined that in solving Question 2, the student takes into account the graphical representation provided in the question and makes a solution through a single variable. When the student's quotation for the multiple variable reasoning level was examined, it was determined that in solving Question 7, the student made a solution by taking into account the distance and time values in the graphical representation provided in the question. The analysis results of the reasoning levels used by the students in the graph structuring questions are presented in Figure 3.

Figure 3

Frequency and Mean Percentage Values for Students' Graph Structuring Levels Based on All Questions



As can be seen in Figure 3, the students used irrelevant reasoning the most and single variable reasoning the least in all 10 questions regarding graph structuring. It was determined that the students did not use the single variable reasoning level only in question 19. It was determined that the students used symbolic reasoning the least in questions 16 and 19. It was also determined that the students used multiple variable reasoning the least in questions 17 and 20. The results show that 51.34% of the students structured constant velocity motion graphs by irrelevant reasoning, 18.76% by symbolic reasoning, 4.22% by single variable reasoning, and 25.6% by multiple variable reasoning. The results of this study suggest that most of the students involved in the research faced significant challenges in constructing constant velocity motion graphs. Sample quotations illustrating the levels of reasoning used by students in graph structuring questions are presented in Table 3.

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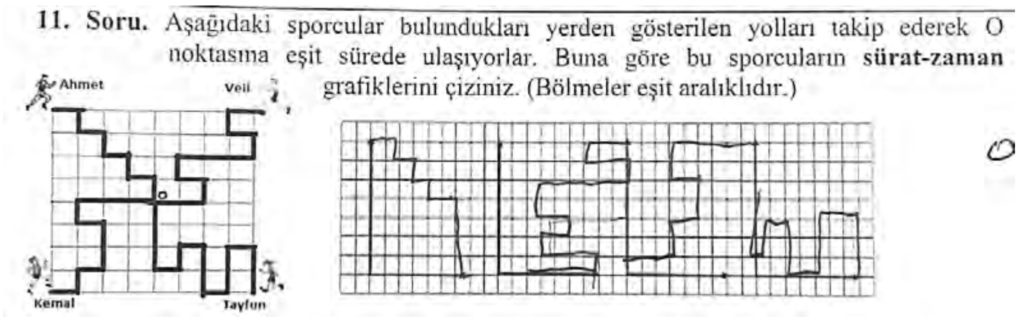
Table 3

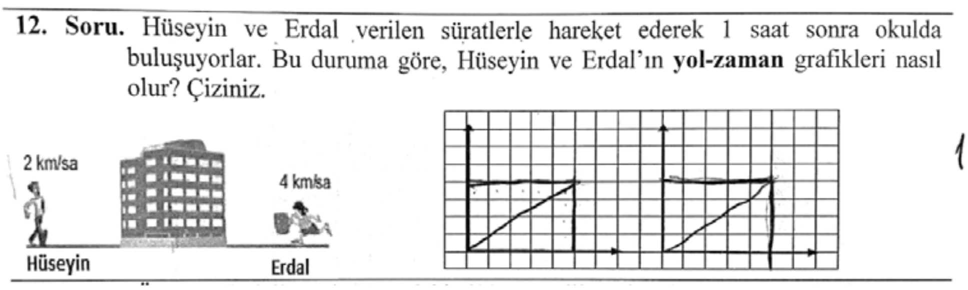
Sample Quotations of The Levels of Reasoning Used by Students in Graph Structuring Questions

Irrelevant Reasoning



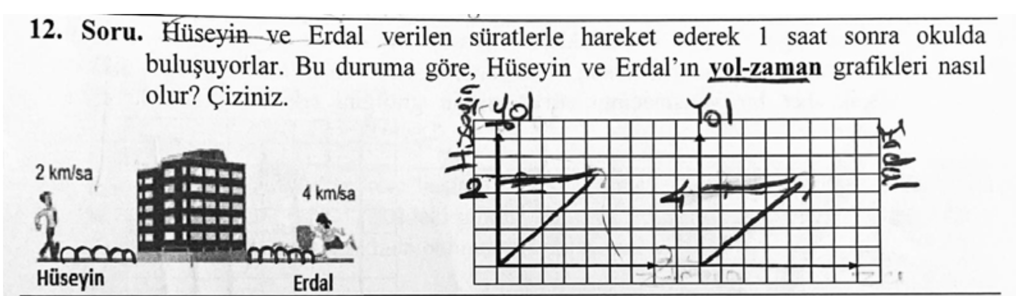
The response of Student 36 to Q11.

Symbolic Reasoning



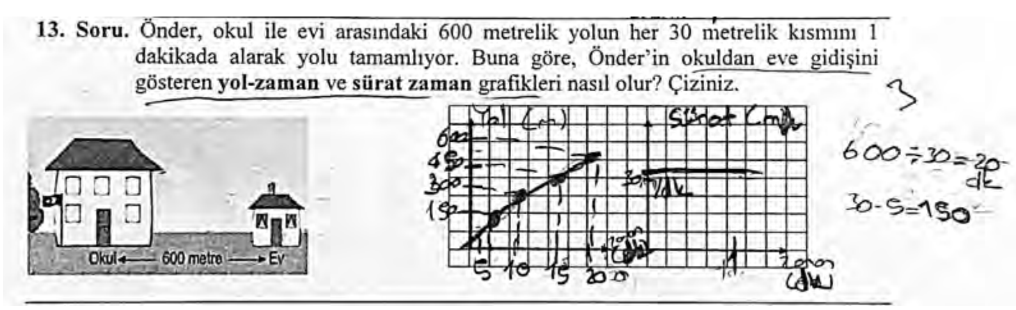
The response of Student 52 to Q12.

Single Variable Reasoning



The response of Student 73 to Q12.

Multiple Variable Reasoning



The response of Student 12 to Q13.

When the student's quotation for the graph structuring questions presented in Table 3 was examined, it was determined that in solving Question 11, the student structured the graph without considering the motion event. When the student's quotation for the symbolic reasoning level was examined, it was determined that in solving Question 12, the student structured the graph only with lines reflecting the definition of the movement

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event. When the student's quotation for the single variable reasoning level was examined, it was determined that in solving Question 12, the student structured the graph by considering only the distance variable. In addition, when the student's quotation for the multiple variable reasoning level was examined, it was determined in solving Question 13, the student structured the graph by considering both the distance and time variables.

Discussion

Understanding motion graphs during lower-secondary is crucial for students to grasp more advanced kinematic concepts in the future. During this stage, students start to explore complex kinematic phenomena that can be represented through graphs. This study aimed to explore how 6th-grade secondary school students, who were encountering constant velocity motion graphs for the first time, understood their interpretation and construction. Below are the discussion and conclusions about the results obtained from the study.

The study's first result indicated that the overwhelming majority of students exhibited irrelevant (illogical) reasoning when interpreting constant velocity motion graphs; that is, they relied on guesswork and incorrect inferences without referencing the motion event. The results revealed that a large number of students exhibited an understanding of explaining the superficial features of the motion phenomenon while analyzing the graphs. Furthermore, it was revealed that a minimal number of students interpreted motion graphs by taking into account more than one variable (distance, time, and velocity). The results indicate that many students perceive and interpret the same type of constant velocity motion graph questions differently. This indicates that students are not able to precisely identify similar strategies in different contexts (Ivanjek et al., 2016).

Interpreting graphical representations of kinematic situations poses a challenge for many students. This difficulty arises because students frequently have difficulty grasping the meaning of the variables shown in motion graphs and the patterns formed by their interactions (Leinhardt et al., 1990). In their research involving lower-secondary students, Lai et al. (2016) found that most students had trouble connecting graph features to scientific concepts, particularly when tasked with interpreting graphs. The students' inability to interpret constant velocity motion graphs, which involve distance, time, and velocity variables, can be attributed to their lack of basic physics knowledge regarding these concepts. Many students who engaged in irrelevant reasoning tended to interpret motion graphs as direct representations of pictures. This is one of the most common errors in graph interpretation. These misconceptions suggest that students perceive the graph as a direct visual representation of the physical phenomenon, rather than interpreting it as abstract quantitative data (Patahuddin & Lowrie, 2019). A frequent issue is the misinterpretation of the graph as an exact representation of motion. One of the primary difficulties students face in analyzing graphs is their tendency to rely on an iconic understanding, where they associate the overall shape of the graph with the visual features of the physical scenario (Duijzer et al., 2019). For instance, students with this type of understanding might interpret a velocity-time graph not as an abstract representation of the relationships among the variables on the axes, but rather as a literal depiction of the object's movement. They also find it challenging to understand why the graph changes when the values on the axes are modified (Ivanjek et al., 2016). Elby (2000) explains that this misunderstanding often stems from students' reliance on intuitive knowledge. It is evident that many students fail to interpret the results represented by the variables on the axes of constant velocity motion graphs (Lowrie & Diezmann, 2007). As a result, they are unable to establish a meaningful connection between the graph and the physical context (Patahuddin & Lowrie, 2019). Furthermore, within the domain of science education, it is clear that most activities and assessments related to constant velocity motion in early secondary school textbooks focus more on problem-solving than on graph interpretation. Additionally, teachers often prefer to use questions that involve solving velocity problems with mathematical formulas, rather than questions focused on graph interpretation. This leads to students frequently not recognizing formulas as mathematical models of physical phenomena and having difficulty interpreting and understanding graphs (Ivanjek et al., 2016). This approach, which emphasizes formulas in teaching constant velocity motion, seems to hinder students' ability to interpret graphs effectively. Consequently, this may prevent students from understanding constant velocity motion graphs and developing the ability for multidimensional thinking.

Zucker et al. (2014) found that science teachers and textbooks focused more on situations or relationships, with no specific reference to graphical representations, leading students to have difficulty understanding graphs. Upon reviewing the literature, it is observed that teachers rarely teach the features of graphs and graph interpretation that students will need in science lessons, and consequently, students encounter challenges in the graph interpretation process (Jarman et al., 2012; Lai et al., 2016). Furthermore, this result indicates that the students'

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mathematical knowledge is insufficient, and they have problems in transferring their mathematical knowledge to physics. Because, when solving constant- velocity motion graphs, students tend to direct the visual decoding process by associating mathematical data with physics concepts. Therefore, in this study, it is understood that many students have significant problems in transferring their mathematical understanding to kinematics. In support of this situation, Wemyss and van Kampen (2013) found evidence that the issue of information transfer across mathematics and physics constitutes a significant barrier to interpreting graphs.

Anderson and Wall (2016) have highlighted that students have often struggled to explain the mathematical relationships between distance, time, velocity, and acceleration. As noted by Lowrie and Diezmann (2007), students' lack of understanding regarding the relationship between the two axes in velocity graphs was again observed in this study. This result aligns with previous research, which shows that insufficient mathematical knowledge affects students' ability to interpret and explain physical concepts and phenomena in velocity-time and distance-time graphs (McDermott et al., 1987). Studies suggest that many students have misconceptions about mathematical units and scales, and face challenges in analyzing graphs due to difficulties in recognizing the connections between graphs and algebraic functions (Leinhardt et al., 1990). This result suggests that motion graphs are not being effectively used in lower-secondary as a tool to improve students' learning in both science and mathematics. Previous research indicates that graphs are among the most powerful tools for helping students integrate mathematics and science, as well as for developing their reasoning skills in science (McHugh et al., 2021). An embodied learning environment is essential for fostering students' reasoning skills in relation to motion graphs. Such an environment offers students the opportunity to move from iconic understanding to multivariable reasoning when interpreting graphical representations of motion (Duijzer et al., 2019). Given these results, it can be inferred that most students in this study did not benefit from such learning approaches during their study of motion.

Another result from the study revealed that the vast majority of students employed irrelevant reasoning while constructing constant velocity motion graphs; that is, they had an understanding that did not take into account the features of the constant velocity motion phenomenon. It was revealed that a large number of students exhibited an understanding based on the superficial properties of the motion event while structuring the graphs. In addition, it was observed that very few students structured their graphs by considering more than one variable (distance, time, and velocity) and a single variable while structuring the graphs. Upon examining the literature, it is clear that students frequently make mistakes in selecting and scaling axes, naming them, and plotting the line that connects the given points during the graph construction stage (Gürakar, 2010; Güven et al., 2012; Tosun, 2021). Additionally, it was found that students have difficulty in structuring graphs because they confuse intervals and punctuation, slope, and height in the graphic structuring process, and perceive graphs as pictures (Bayazıt, 2011; Leinhardt et al., 1990). Bruno and Espinel (2009) found that students faced difficulties in the process of representing continuous and discontinuous data with appropriate graphs and in the process of converting raw data into graphs. Aydın and Tarakçı (2018) discovered that pre-service science teachers also struggled with identifying the starting point of the graph, scaling the axes, and integrating the values during the graph construction process. Likewise, Yayla and Özsevgeç (2015) concluded that students had difficulty in determining dependent and independent variables on the axes, connecting the points, and drawing curves or lines when constructing graphs. In their study with 8th-grade students, Zorluoğlu and Türkmen (2020) also found that the students' graph structuring skills were at a low level. Students are not able to draw graphs according to the data and find the graph structuring process very complicated (Kranda & Akpınar, 2020). Students have more difficulty in graph structuring questions than in graph reading and interpretation questions (Aydın & Tarakçı, 2018; Bursal & Yetiş, 2020; Yayla & Özsevgeç, 2015). In their past learning experiences, students generally encountered multiple-choice, graphic reading, and interpretation questions, and since they did not encounter question types that they could structure graphs, they have difficulty in structuring graphics (Tosun et al., 2023). It can be said that the weakness in students' understanding of creating constant velocity motion graphs, as also identified in this study, is generally attributed to the emphasis on kinematic topics in science classes being more verbally oriented and the problems used in these classes being solved mathematically. Therefore, the lack of early-stage lower-secondary curriculum content related to graph structuring may have led to this result. In addition, the result that students demonstrated significantly higher levels of graph structuring with multiple variables compared to graph interpretation can be accounted for by the fact that students make mathematical combinations based on the x and y axes, rather than considering more than one variable within a kinematic understanding when drawing graphs.

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The result here does not mean that the students have correctly structured the constant velocity motion graphs. While students use more than one variable in the context of kinematics here, it is understood that they consider these variables as x and y coordinates and see them as a combination or drawing on axes rather than thinking kinematically. This study result indicates that the kinematic terminology used by students in constructing constant velocity motion graphs lacks a scientific basis. It can be stated that this situation is the main reason for students' weaknesses in structuring graph coordinates and graph areas. This result aligns with the results of the study conducted by Duijzer et al. (2019), which discovered that graphing tasks required students to exhibit a high level of cognitive reasoning.

Conclusions and Implications

This study showed that students in the first step of secondary school have great difficulties in using and structuring constant velocity graphs, which is the most essential subject of kinematics in science. It also appears that students' understanding about graph questions is often iconic and detached from context. Considering the results obtained, it is believed that it is important to identify the underlying causes of students' deficiencies (such as teacher inadequacy, lack of materials, etc.). Additionally, the study was conducted before the changes to the curriculum in Türkiye. In this context, determining students' ability to construct and interpret graphs related to constant velocity motion becomes crucial. The results obtained from the study may provide guiding data for curriculum developers. Based on these data, it is thought that they can guide the design of instructional materials aimed at improving the teaching process and the selection of appropriate teaching methods. The deficiencies in students' abilities to construct and interpret graphs related to constant velocity motion could negatively affect their spatial learning skills. Considering the spiral structure of science and physics education programs in Türkiye, students' learning deficiencies at lower educational levels may adversely impact their ability to construct and interpret different types of graphs, such as the acceleration-time graph, in later stages. In the early stages of secondary school, students should be given the opportunity to participate in practice experiences representing real-life situations on constant velocity motion graphs and to make measurements and inferences based on real data. Science teacher training should aim to develop pedagogical skills to support effective kinematic graphic teaching. Future studies conducting in-depth interviews with students who have an irrelevant reasoning level on the subject of constant velocity movement are recommended.

Limitations

The primary limitation of the present study is that it was conducted in only one province, with students from a single school. Expanding the study to include additional provinces and schools would help to strengthen the validity of these results. Furthermore, the results were derived solely from data collected through the constant velocity motion graph form. To further substantiate these results, in-depth student interviews are necessary.

Declaration of Interest

The authors declare no competing interest.

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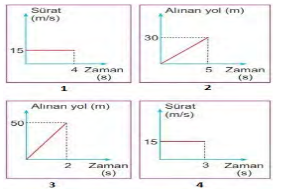
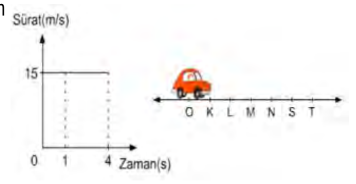
Appendix

Form questions for graph construction (drawing) and interpretation

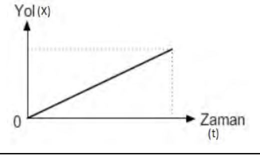
Q1. Tolga asked his students to draw velocity-time and road-time graphs for different vehicles. Accordingly, which student's vehicle traveled the least road at the end of 5 seconds? Explain.



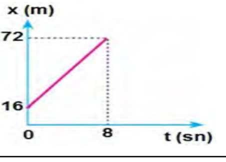
Q2. The velocity-time graph of a vehicle traveling on a linear road with equal divisions starting from point O is as shown in the figure. Accordingly, if the vehicle is at point K in the 1st second, at which point will it be in the 4th second? Explain.



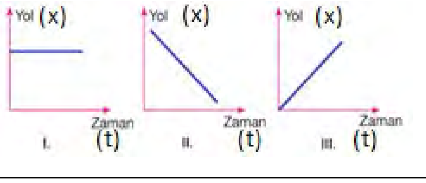
Q3. The change in the road traveled by a vehicle over time is given in the graph. According to this, what is the relationship between time and the road by the vehicle? Also, what can we say about the velocity of the vehicle? Explain.



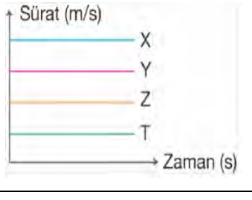
Q4. A road-time graph of a moving person is given. According to the graph, what can we say about the initial position and the position of the mover at the 8th second? Also, what can you say about the velocity of the moving person? Explain.



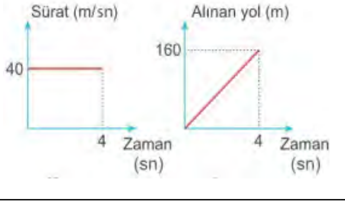
Q5. Below is a graph of the time and road by three vehicles. What can we say about the velocities of these three vehicles? Explain.



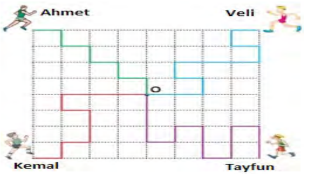
Q6. According to the graph below, what can be said about the velocities of vehicles X, Y, Z and T? Also, what can be said about the road taken by these vehicles in equal time? Explain.



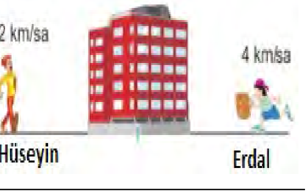
Q7. The velocity-time graph of vehicle K and the road-time graph of vehicle L are given below. In this case, what can we say about the velocities of K and L vehicles and the roads they traveled at the end of 4 seconds? Explain.



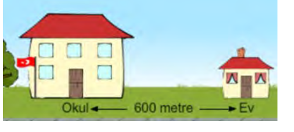
Q11. The following athletes reach point O in equal time by following the roads shown. Accordingly, draw the velocity-time graphs of these athletes. (The divisions are equally spaced.)



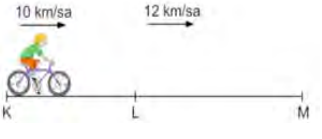
Q12. Hüseyin and Erdal move at the given velocities and meet at the school after 1 hour. According to this situation, what are the road-time graphs of Hüseyin and Erdal? Draw them.



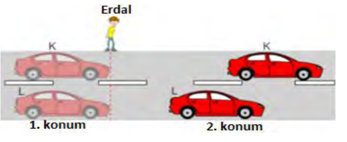
Q13. Önder completes the 600-meter route between his school and home in 1 minute for every 30 meters. Accordingly, what is the road-time and velocity-time graph of Önder's journey home from school? Draw them.



Q14. A cyclist traveling from point K to point L travels from K-L in 3 hours and from L-M in 2 hours. Draw the road-time graph showing the cyclist's travel in the K-M interval.



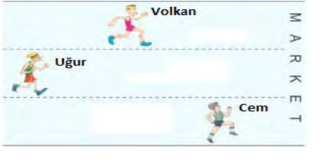
Q15. Erdal observes the motion of vehicles moving at constant velocity on a straight road. After the vehicles pass through the 1st position at the same time, they pass through the 2nd position at the same time with vehicle K in front and vehicle L behind as shown in the figure. According to this situation, how can the velocity-time graph of K and L vehicles be? Draw it.



Q16. The table shows the road, time and velocity values of K, L, M and N vehicles. According to this situation, find the values of the empty spaces in the table. Also, draw the graphs of velocity-time for vehicle K, road-time for vehicle L, and velocity-road graphs for vehicles M and N.

Vehicle	Road (m)	Time (sn)	Velocity (m/sn)
K	20	4	....
L	....	10	3
M	60	12	....
N	24	....	4

Q17. Volkan, Uğur and Cem run towards the supermarket from their positions. Uğur reaches the supermarket first, then Volkan and finally Cem. Considering this situation, show the velocity-time graph of each competitor on a single graph.



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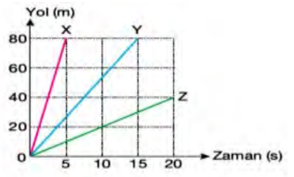
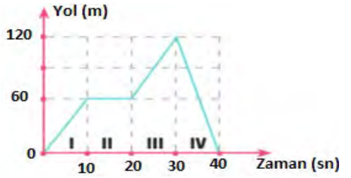
Q8. The road-time graphs of vehicles X, Y and Z are given below. According to this situation, what can we say about the velocities of the vehicles? Explain.



Q18. A minibus traveling at a constant velocity at 09:00 p.m. picks up Tuğra at 09:10, Elis at 09:20 and Arya at 09:30. Since the distance between the stops is 300 m, draw the graph of the time and road traveled by the minibus.

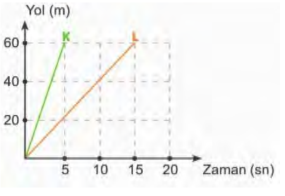
Q9. What can we say about the motions of the motion in intervals I, II, III and IV given the road-time graph? Explain.



Q19. The values showing the road traveled and the elapsed time of a bus traveling on a straight road are given in the table. Draw the road-time, velocity-time and road-velocity graphs of the bus according to this table.

Road (km)	0	50	100	150	200
Time (sa)	0	3	6	9	12

Q10. What can we say about the velocities of the vehicles K and L whose road-time graphs are given? Also, when these vehicles are moving in the same direction, what can be said about the distance between them at the end of the 5th second? Explain.



Q20. Show the velocity-time graphs of the vehicles P, R and S whose road-time graphs are given.

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