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High School Students' Comprehension of Kinematics Graphs wıth Peer Instruction Approach

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Abstract

The present study investigated the effects of the peer instruction approach on high school students' kinematics graphs interpretation skills and understanding of kinematics graphs. The study was conducted with 65 high school students from two groups. The first group was the experimental group and the second group was the control group. 32 students of the experimental group were taught using the peer instruction approach while 33 students of the control group were taught using the conventional teaching method. The data of the study were collected with the Test of Understanding Graphs in Kinematics. The results of the study showed that the peer instruction approach had a more positive effect on students' kinematics graphs interpretation skills and understanding of kinematic graphs than the conventional teaching method. In addition, there was a reasonable change in students' understanding of graphs and graphical thinking processes in the experimental group The students' understanding of graphs and graphical thinking processes did not change significantly in the control group. The results of the study revealed that the peer instruction approach can be used with little effort to assess and improve high school students' academic achievement in physics classes.

Key words: high school; kinematics graphs; peer instruction approach; physics education

INTRODUCTION

The researchers noticed that many students did not learn enough physics using conventional teaching methods (Bao & Koeing, 2019; Mariati, Betty, & Sehat, 2017; Pratiwi & Muslim, 2016; Sari, Santyasa, & Gunadi, 2021; Wartono, Diantoro, & Bartlolona, 2018). Many research revealed that many students leave physics courses with the same misunderstanding when they started these courses (Gok, 2015; Walde, 2017). Most students struggle with problem solving, recognizing basic concepts, and understanding graphs in the conventional teaching methods (Reddy & Panacharoensawad, 2017; Haratua & Sirait, 2016; Walde, 2017). For many students, it is not important to use the physical representations (vector diagrams, free-body diagrams, graphs, ray diagrams, etc.) in problem solving (Wong, Poo, Hock, & Kang, 2011). To address the drawback of the conventional teaching method, many teaching methods have been used to enhance students' understanding in physics classes (Abdjul, Ntobuo, & Payu, 2019; Bao & Koeing, 2019; Batlolona, Singerin, & Diantoro, 2019; Nisa, Jatmiko, & Koestiari, 2018). One of the many methods was peer instruction approach (PIA).

Mazur and Watkins (2010) described the PIA as an "interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material." The PIA is generally an interactive learning activity based on conceptual learning and peer-to-peer discussion (Gok, 2015). The PIA is described as a student-centred approach based on the constructivist approach (Gok, 2015). Peer instruction approach is typically used to solve physics problems, understand the fundamental concepts, and explore student misconceptions by using multiple-choice test items and classroom response systems or flashcards "colored cards" (Gok, 2015). Turpen & Finkelstein (2009) found that peer instrcution approach involves three sections. The first section is set-up, the second section is response, and the final section is the resolution/discussion of concept tests/problems. The details of these sections were described in the method of that research.

The PIA offers several benefits to both students and teachers by changing conventional teaching methods (Gok, 2015; Crouch & Mazur, 2001). Students can explore their misconceptions and misunderstandings by discussing them with their classmates (Nielsen, Hansen-Nygård, & Stav, 2012). At the end of the group discussion, they can revise their ideas. Finally, the teacher explains the concepts and/or principles to the students by exploring the students' responses in the class discussions (Brooks & Koretsky, 2011; Tullis & Goldstone, 2020; Smith, Wood, Krauter, & Knight, 2011).

Many studies have been conducted on the peer instruction approach. The studies examined found that the PIA enhances students' conceptual learning, problem-solving skills, and logical thinking. In addition, the studies examined showed that the PIA increases students' motivation, attitude, and attendance regardless of their background and gender (Gok, 2013; Gok, 2014; Al-Hebaishi, 2017; Zang, Ding, & Mazur, 2017). However, it appears that the PIA has not been used in the literature for teaching kinematic graphs.

Therefore, the results of this study will fill the gap in the literature and guide educators and teachers who will conduct research on this subject. It will also provide guidance to the students who have difficulties in understanding and interpreting PIA kinematic graphs.

The use of graphs is very important for understanding some fundamental concepts (velocity, acceleration, etc.) in physics (Planinic, Milin-Sipus, Katic, Susac, & Ivanjek, 2012). Beichner (1994) emphasized "physics teachers tend to use graphs as a sort of second language, assuming their students can extract most of their rich information content." Also he reported "graphs summarize large amounts of information while still allowing details to be resolved." Physics students prefer problem solving to understanding and interpreting graphs in kinematics. This is because it is easier to solve problems than to understand kinematics graphs. Generally, many students follow problem solving strategy steps to solve problems without understanding the kinematics problems (Gok, 2015). The problem-solving strategy steps are very important for students in physics. Also the use of multiple representations (diagrams, schemes, vector, graphs, etc.) plays a crucial role in physics (Celik & Pektas, 2017; De Cock, 2012; Nixon, Godfrey, Mayhew, & Weigert, 2016; Savinainen, Nieminen, Makynen, & Viiri, 2013).

The ability to construct and interpret kinematics graphs is very important in the development of scientifically literate students (Ergul, 2018; Manurung, Mihardi, Rustaman, & Siregar, 2018; Nixon et al., 2016; Petrova, 2016; Theasy, Wiyanto & Sujarwata, 2018). Kinematics graphs in one dimension have position, velocity, and acceleration as the ordinate and time as the abscissa. Interpreting kinematics graphs is important for analyzing and understanding kinematic concepts (velocity, acceleration, position, slope, area, height, etc.). Therefore, students are expected to fully understand the kinematics concepts and be able to solve graphical problems after understanding the basic kinematics concepts (Zavala, Tejeda, Barniol, & Beichner, 2017). Many studies (Antwi, Savelsbergh, & Eijkelhof, 2018; Ivanjek, Susac, Planinic, Andrasevic, & Milin-Sipus, 2016; Maries & Singh, 2013; Planinic, Ivanjek, & Susac, 2013; Vaara & Sasaki, 2019; Zavala et al., 2017) have reported that students have difficulty in understanding kinematics graphs, changing from one kinematics graphs to another, calculating and interpreting an area, comprehending the meaning of the slope of a line, determining the height of a point on the line, relating graphs to physics concepts, interpreting curved graphs differently from rectilinear graphs, making a connection between graphs and a particular subject, identifying specific events in graphs of velocity-time, acceleration-time, and position-time, analyzing deceleration and acceleration. Some studies (Amin et al., 2020; Bektaslı & White, 2012) have found that many students have great difficulty in reading kinematic graphs, so there is a close relationship between logical thinking and the skill to interpret kinematics graphs.

Students are expected to follow a few steps when learning kinematics graphs, using the peer instruction approach. In the first step, they are expected to understand the basic kinematics concepts; in the second step, they are expected to determine the desired and given variables in the graphs; in the third step, they are expected to make a connection between the concepts and the graphs; in the fourth step, they are expected to interpret the graphs in terms of the object being represented; and in the last step, they are expected to explain the graphical solution. Consequently, the peer instruction approach can help students understand basic kinematic concepts and kinematic graphs. In this approach, students can establish a close relationship between their graphing skills and their reasoning skills.

Many studies (Gok, 2015; Gok, 2014; Al-Hebaishi, 2017) have examined the effects of peer instruction approach on students' conceptual learning in physics classrooms. There are no studies in the literature on the understanding of kinematics graphs through the use of peer instruction approach. Therefore, the results of this study will contribute to the literature and enlighten researchers conducting research on this topic. The research questions studied were:

1. Is teaching kinematics graphs with the PIA effective in improving students' kinematics graphs interpretation skills and understanding of kinematics graphs?
2. Are there differences between the interpretation skills and understanding of kinematics graphs in female and male students?

METHOD

In this study a quasi-experimental design (two groups, pretest-posttest) was used. Physics class for high school students, divided into an experimental and a control group, using two different teaching methods. The experimental group was taught using the PIA. The control group was taught by the conventional teaching method (CTM). The application processes of the methods used in the research are explained in detail below.

Participants

The sample of this study consisted of 65 high school students enrolled 9th grade. The high school education is compulsory and in Turkey lasts four years (from 9th class to 12th class). The experimental group consisted of 32 students (13 female and 19 male) and the control group consisted of 33 students (12 female and 21 male).

Procedures of Teaching Approaches

The study was conducted at a public high school in western Turkey. The groups were taught by the same physics teacher for five weeks. (The lectures lasted about 2 hours per week.) The main objective of the physics course was to familiarize the students with the definition and explanation of kinematic concepts and kinematic graphs. An experienced and volunteer physics teacher was trained with peer instruction approach by the researcher. The teacher taught the same content and graphs to both groups. Two or three graphing tests were solved in one lesson. Sample questions were given in the Appendix.

The procedure of the PIA in the experimental group was as follows: a) The teacher gives many short presentations on basic kinematic concepts in each course. b) The teacher shows two or three graphical tests after each short presentation. c) Students are given time to think about individual answers. They are not allowed to talk to each other. d) They report their individual answers. e) Colored cards ("red for A", "yellow for B", "green for C", "blue for D", and "white for E") are used during the voting process without using a Classroom Response System or a "clicker" to report student responses. f) They discuss their answers with their peers. g) They share their revised answers. h) The teacher gives general feedback to the students by explaining the correct answer. The procedure of the PIA is represented in Figure 1. When the number of correct answers (CA) reaches 30-70% of the answers, the teacher initiates the graphical solution by making a whole class discussion. If the number of correct answers is less than 30%, the graph is explained again.

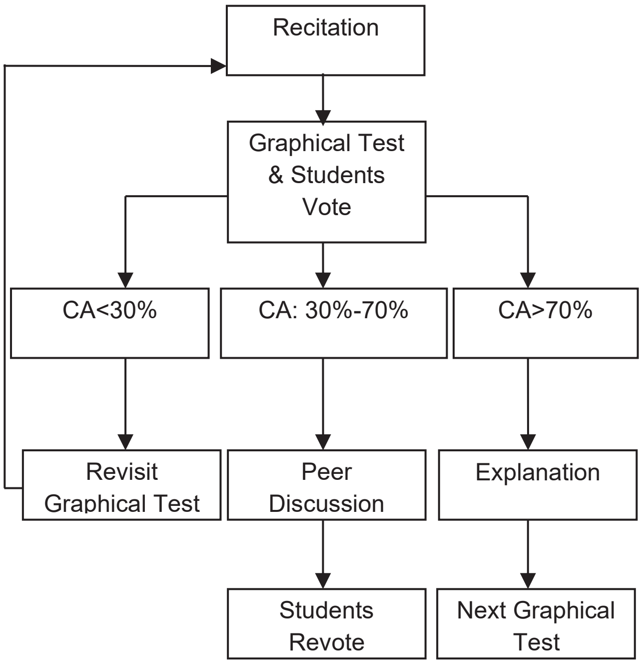

Figure 1. The procedure of PIA

The procedure of the CTM was as follows: The teacher gives several short presentations about basic concepts in each lesson. After the presentations, the teacher shows two or three graphic tests. Students are given time to reflect on individual answers. They are not allowed to talk to each other. They give their individual answers using colored cards. Finally, the teacher evaluates the students' answers.

Data Collection

The Test of Understanding Graphs in Kinematics (TUG-K) was administered to the groups as a pretest and posttest. The TUG-K, which assessed students' kinematic concepts (velocity, acceleration, displacement, etc.), contained 21 multiple-choice questions with five response options. The results of some statistical analyses (Beichner, 1994) of the original TUG-K were reported as follows: The point-biserail coefficients of the items of the TUG-K were greater than 0.20. The average of the point- biserail coefficient was 0.83. The value of KR-20 (Kuder and Richardson) for the TUG-K was greater than 0.70. The KR -20 value of the TUG-K was 0.83. The Ferguson's Delta of the TUG-K was greater than 0.90. The value for the TUG-K was 0.98. The Ferguson's Delta is an acceptable minimum of 0.70. The item discrimination index of the TUG-K' items was greater than 0.30. The average of the item discrimination index was 0.36. For more comprehensive statistical analyzes of the test, Beichner's studies can be reviewed (Beichner, 1994; Zavala, Tejeda, Barniol, & Beichner, 2017).

Data Analysis

Student responses related to the pretest and posttest of the TUG-K were analyzed using using descriptive statistics (mean, standard deviation), fractional gains (g), and analysis of variance (ANOVA) by SPSS 21. ANOVA was used to control whether the means of two groups differ from each other significantly. After determining that the difference between the pretest means of the experimental and control groups was not significant ($p>0.05$), ANOVA was performed to test the main effect of treatment on the posttest means of the experimental and control groups. The TUG-K results were analyzed using non-parametric statistics (Mann-Whitney U test) to determine the gains of students in the EG and CG. The Mann-Whitney U test was used to compare the differences between the experimental group and control group when the dependent variable was continuous but not normally distributed in the research.

Hake's formula was also used to calculate fractional gains of the experimental and control group students (Hake, 1998). He defined three specific ranges ("high gain; $g \geq 0.7$," "medium gain; $0.7 = g \geq 0.3$," and "low gain; $g < 0.3$") for fractional gains.

RESULT AND DISCUSSION

Descriptive statistics of the groups' pretest results show that the results are similar at the baseline (Table 1). Analysis of variance (ANOVA) showed that the pretest results of the groups were not statistically significant difference, F(1-63)=1.18, p>0.05 while the posttest results of the groups were statistically significant difference, F(1-63)=70.90, p<0.05. The experimental group had a medium gain (g=0.63) and the control group had a low gain (g=0.30). The results revealed that peer instruction approach improved the skills of students in the experimental group to interpret kinematics graphs and their understanding of kinematics graphs.

Table 1. The TUG-K scores of the students in the groups

			Pretest		Posttest		Gain
Group		N	M	SD	M	SD	g
Female	EG	13	2.84	0.55	10.07	0.49	0.40
	CG	12	3.00	0.60	7.41	0.79	0.24
Male	EG	19	2.73	1.14	17.41	1.42	0.80
	CG	21	3.03	0.70	8.99	1.41	0.33
Total	EG	32	2.78	0.94	14.43	3.83	0.63
	CG	33	3.02	0.66	8.42	1.43	0.30

Note: M: Mean; SD: Standard Deviation

Figure 2 and Figure 3 show the differences between the peer instruction approach and the conventional teaching method and gender after and before using of the TUG-K.

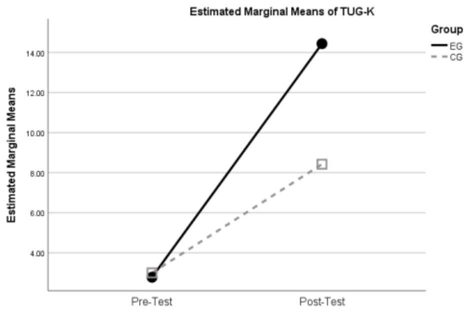

Figure 2. The differences between the groups' pretest and posttest scores

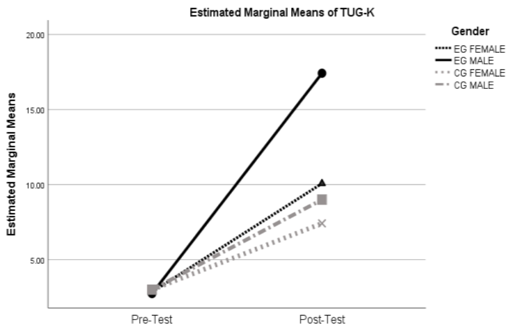

Figure 3. The differences between the female and male students' scores in the groups

The figures indicate that the gains of female and male students in the EG are higher than the gains of female and male students in the CG. The results revealed that the PIA is more effective than the CTM. The distribution of correct answers of female and male students in the groups is shown in Figure 4 and Figure 5.

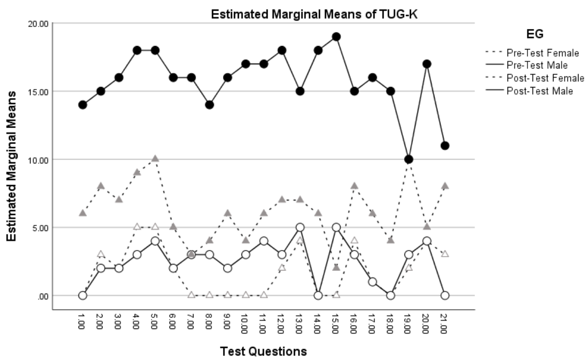

Figure 4. The correct answers of the experimental group students according to the test questions.

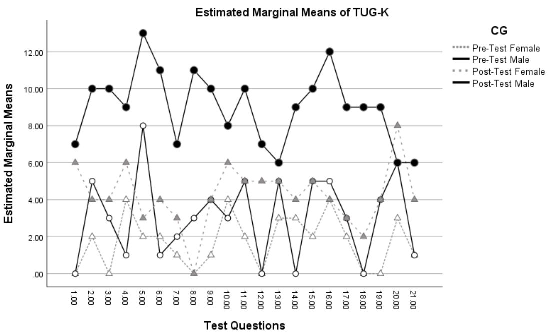

Figure 5. The correct answers of the control group students according to the test questions (Note: The filled marks indicate the posttest, and the hollow marks indicate the pretest).

The figures show the distributions of students' correct answers in relation to the TUG-K. The results indicate that the correct answers of the students in the EG were higher than the correct answers of the students in the CG. The number of correct answers of male students was higher than the number of correct answers of female students in both groups.

The Mann-Whitney U test was used to compare the results of the female and male students in the pretest and posttest groups. The results are presented in Table 2 and Table 3. There is no statistically significant difference between the pretest scores of female students (U=68, p>0.05) and the pretest scores of male students (U=170.05, p >0.05) in the groups. But there is a statistically significant difference between the posttest scores of female students (U=0.50, p<0.05) and the posttest scores of male students (U=0.00, p<0.05) in favor of the EG.

Table 2. The female and male students' TUG-K pretest scores in the groups

			Pretest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	12.33	159.00	68	0.50
	CG	12	13.83	166.00		
Male	EG	19	18.97	360.50	170.05	0.40
	CG	21	21.88	459.50		

Table 3. The female and male students' TUG-K posttest scores in the groups

			Posttest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	18.96	246.50	0.50	0.00
	CG	12	6.54	78.50		
Male	EG	19	31.00	589.00	0.00	0.00
	CG	21	11.00	231.00		

Note: MR: Mean Rank; SR: Sum of Ranks

When analyzing the TUG-K based on the questions, the TUG-K questions could be divided into logical questions (TUG-KL) and arithmetic questions (TUG-KA). The TUG-KA questions include 4-7, 16-18, 20 questions. The rest of the test questions include the TUG-KL. The results of the identified sections were analyzed in detail.

Table 4 shows the descriptive statistics related to the TUG-KL results and the fractional gain of students in the groups. When the students' scores are compared, the students' pretest scores in the groups appear to be similar, while the students' posttest scores in the EG are higher than the students' posttest scores in the CG. The fractional gains of female and male students in the EG are "medium" and "high", respectively. In the CG, the fractional gains of female and male students are "low" and "medium", respectively. The results reveal that the peer instructional approach seemed to help the students in the experimental group interpret the kinematics graphs and understand the fundamental concepts of kinematics.

Analysis of variance (ANOVA) shows that the pretest scores of the groups are not statistically significant difference, F(1-63)=0.75, p>0.05, while the posttest scores of the groups are statistically significant difference, F(1-63)=51.742, p<0.05, in favor of the EG.

Table 4. Descriptive statics of the groups' TUG-KL scores

			Pretest		Posttest		Gain
Group		N	M	SD	M	SD	g
Female	EG	13	1.23	0.83	6.23	0.83	0.42
	CG	12	1.50	0.67	4.66	1.23	0.27
Male	EG	19	1.68	1.15	10.52	1.26	0.78
	CG	21	1.80	0.81	5.38	1.80	0.31
Total	EG	32	1.50	1.04	8.78	2.40	0.63
	CG	33	1.69	0.76	5.12	1.63	0.43

Figure 6 shows the differences between the peer instruction approach and the conventional teaching method and gender after and before using the TUG-KL.

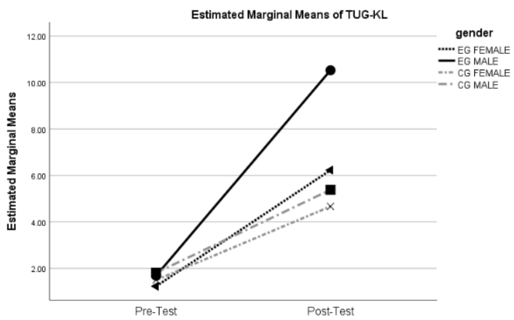

Figure 6. The differences between the students' TUG-KL pretest and posttest scores in the groups

The Mann-Whitney U test was used to compare students' TUG-KL pretest and posttest scores in the groups. The results of TUG-KL are shown in Table 5 and Table 6. There is no statistically significant difference between the pretest scores of female students ($U=59.50$, $p>0.05$) and the pretest scores of male students ($U=177.00$, $p>0.05$) in the groups. But there is a statistically significant difference between the posttest scores of female students ($U=24.50$, $p<0.05$) and the posttest scores of male students ($U=5.00$, $p<0.05$) in favor of the EG.

Table 5. The female and male students' TUG-KL pretest scores in the groups.

			Pretest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	11.58	150.50	59.50	0.27
	CG	12	14.54	174.50		
Male	EG	19	19.32	367.00	177.00	0.51
	CG	21	21.57	453.00		

Note: MR: Mean Rank; SR: Sum of Ranks

Table 6. The female and male students' TUG-KL posttest scores in the groups.

			Posttest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	17.12	222.50	24.50	0.00
	CG	12	8.54	114.50		
Male	EG	19	30.74	584.00	5.00	0.00
	CG	21	11.24	236.00		

Table 7 shows the descriptive statistics related to the TUG-KA results and the fractional gain of students in the groups. The comparison of the students' scores indicates that the pretest scores of the students in the groups are similar, while the posttest scores of the students in the EG are higher than the posttest scores of the students in the CG. The fractional gains of female and male students in the EG are "medium" and "high", respectively, while the fractional gains of female and male students in the CG group are "low" and "medium". The same results reveal that the peer instruction approach seems to help the students in the experimental group to interpret the kinematics graphs and understand the fundamental concepts of kinematics.

Analysis of variance (ANOVA) showed that the pretest scores of the groups were not statistically significant difference, $F(1\text{-}63)=0.07$, $p>0.05$, while the posttest scores of the groups were statistically significant difference $F(1\text{-}63)=36.288$, $p<0.05$, in favor of the EG.

Table 7. Descriptive statics of the groups' TUG-KA scores

			Pretest		Posttest		Gain
Group		N	M	SD	M	SD	g
Female	EG	13	1.61	0.76	3.84	1.06	0.34
	CG	12	1.50	0.67	2.75	0.96	0.19
Male	EG	19	1.05	0.62	6.89	0.93	0.84
	CG	21	1.23	0.83	3.61	1.39	0.35
Total	EG	32	1.28	0.72	5.65	1.80	0.65
	CG	33	1,33	0.77	3.30	1.31	0.29

Figure 7 shows the differences between the peer instruction approach and conventional teaching method and gender after and before using the TUG-KA.

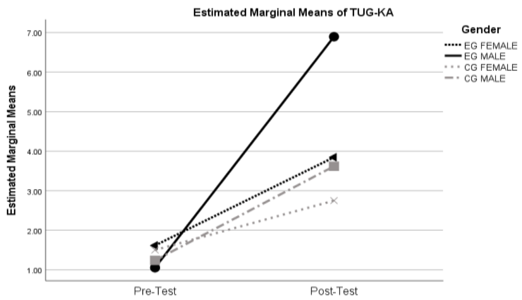

Figure 7. The differences between the students' TUG-KA pretest and posttest scores in the groups

The Mann-Whitney U test was used to compare students' TUG-KA pretest and posttest scores in the groups. The results of TUG-KA are shown in Table 8 and Table 9. There is no statistically significant difference between pretest scores of female students ($U=72.00$, $p>0.05$) and the pretest scores of male students ($U=174.00$, $p>0.05$) in the groups. But there is a statistically significant difference between the posttest scores of female students ($U=35.50$, $p<0.05$) and the posttest scores of male students ($U=5.00$, $p<0.05$) in favor of the EG.

Table 8. The female and male students' TUG-KA pretest scores in the groups

			Pretest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	13.46	175.00	72.00	0.71
	CG	12	12.50	150.00		
Male	EG	19	19.16	364.00	174.00	0.44
	CG	21	21.71	456.00		

Table 9. The female and male students' TUG-KA posttest scores in the groups

			Posttest			
Gender	Group	N	MR	SR	U	p
Female	EG	13	16.19	210.50	35.50	0.01
	CG	12	9.54	114.50		
Male	EG	19	30.74	584.00	5.00	0.00
	CG	21	11.24	236.00		

When the results of the research are generally discussed, some inferences can be asserted as follows. The TUG-K, TUG-KL, and TUG-KA gains of the female and male students in the EG through the implementation of peer instruction approach are higher than the TUG-K, TUG-KL, and TUG-KA gains of the female and male students in the CG.

When the students' answers according to the TUG-KL questions are evaluated, the experimental group students' skills to interpret the kinematics graphs and to understand the kinematics graphs based on determination change in velocity and acceleration are higher than the control group students' skills to interpret the kinematics graphs and to understand the kinematics graphs. Besides, when the students' answers according to the TUG-KA questions are examined, the experimental group students' problem solving skills on the given graphs based calculations (area, slope, etc.) are higher than the control group students' problem solving skills.

When the results of the present research were generally discussed, the PIA was found to be more effective on students' cognitive skills (analyze, remember, solve, understand, etc.) according to the CTM. The results of several studies (Antwi, Raheem, & Aboagye, 2016; Ayop & Ismail, 2019; Budini, Marino, Carreri, Camara, & Giorgi, 2019; Chalermchat & Wuttiprom, 2015; Gok & Gok, 2017; Gok, 2015; Nascimento & Oliveira, 2020; Tullis &

Goldstone, 2020; Zang et al. 2017) have supported the results of the present research. The results have revealed that the peer instruction approach was more effective on female and male students' skills of logical and arithmetic problem solving, conceptual learning understanding and interpretation at the kinematics graphs.

CONCLUSION

The fundamental findings of the research revealed that the peer instruction approach had more positive effect on students' kinematics graphs interpretation skills and understanding of students on kinematics graphs than conventional teaching method. The PIA used in developing high school students' graphical skills was quite effective.

In the light of the results of this study, physics teachers can use the peer instruction approach when explaining kinematic graphs to their students. Furthermore, the implementation of the PIA was both simple and affordable for physics teachers.

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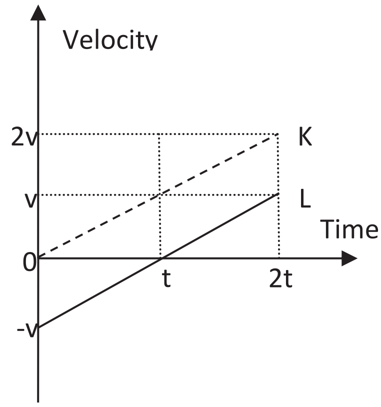
Appendix

Sample Question 1:



The velocity-time graph of the K and L vehicles, which are side by side at the beginning and moving in a linear path, is as in the figure. Which of the following statements is correct according to the graph given?

a) After t time, the vehicles come together again.

b) The vehicles are constantly moving away from each other.

c) The vehicles always move in the same direction.

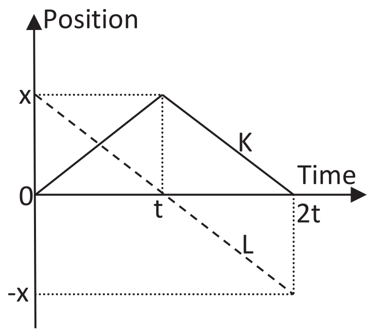
d) During 2t the displacements of the vehicles are equal.

e) The vehicles approach each other between t and 2t.

Students' Answer: Before and After PIA in the EG and CTM in the CG

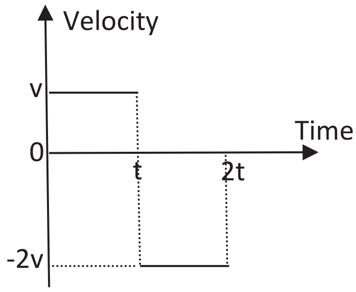
	BEFORE PIA	AFTER PIA	CTM
	EG	EG	CG
FEMALE	6(46%)	10(77%)	5(42%)
MALE	10(53%)	16(84%)	12(57%)
TOTAL	16 (50%)	26(81%)	17(52%)

Sample Question 2:

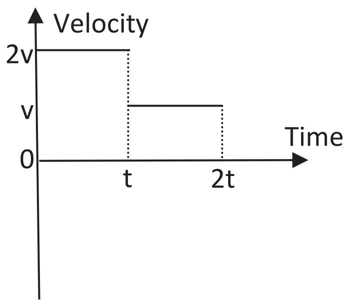


Vehicles K and L, whose position-time graphs are as shown in the figure, move on a straight path. According to the graph given, which of the following would be the change in velocity of vehicle L relative to vehicle K with time?

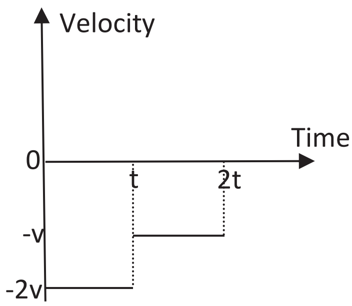
a)



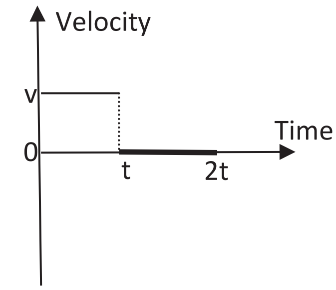
b)



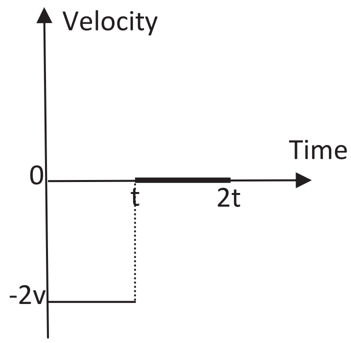
c)



d)



e)



Students' Answer: Before and After PIA in the EG and CTM in the CG

	BEFORE PIA	AFTER PIA	CTM
	EG	EG	CG
FEMALE	4(31%)	9(69%)	5(42%)
MALE	7(37%)	17(89%)	11(52%)
TOTAL	11 (34%)	26(81%)	16(48%)