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THE EFFECTS OF COMBINING PEER DISCUSSION AND ISOMORPHIC PROBLEMS ON HIGH SCHOOL STUDENTS' ACADEMIC ACHIEVEMENTS

Abstract: The present study investigated the effects of combining peer discussion and isomorphic problems on high school students' graph understanding and conceptual learning. The study was conducted on the subjects of kinematics and Newton's Laws of Motion with 67 high school students from two groups. The experimental group consisted of 34 while the control group combined with 33 students. The students in the experimental group were taught using the peer discussion with isomorphic problem (PD-IPs) approach while the students in the control group were taught using the traditional teaching method. The research data were collected using Force Motion Achievement Test (FMAT) which was composed by selecting multiple-choice questions from some standardized tests (Force Concept Inventory, Mechanic Baseline Test, Test of Understanding Graphs in Kinematics). The FMAT includes 25 multiple-choice questions. 11 of these questions were related to graph understanding, the rest of the questions were related to conceptual learning. The research results showed that the PD-IPs approach had a more positive effective on students' understanding of graphs and conceptual learning than the traditional teaching method. The findings indicate that the implementation of the PD-IPs approach requires minimal effort while demonstrating the potential to evaluate and improve high school students' academic performance in the field of physics education.

Keywords: Conceptual learning, graph understanding, isomorphic problem, peer discussion, physics education

INTRODUCTION

Conceptual learning and understanding of multiple representations (motion diagram, free-body diagrams, graphs, etc.) are very important for teaching physics (Gok & Gok, 2022; Munfaridah, Avraamidou, & Goehdart, 2021; Nixon, Godfrey, Mayhew, & Wiegert, 2016). Physicists use alternative teaching approaches instead of traditional teaching methods to provide an understanding of the fundamental concepts of physics in physics classes. Many students also seek to learn by understanding, questioning and interpreting the fundamental concepts of physics. Research has shown that traditional teaching methods are not effective for conceptual learning and understanding of multiple representations among students (Bao & Koeing, 2019; Sari, Santyasa, & Gunadi, 2021). Research (Gok & Gok, 2022; Suppapittayaporn, Emarat., & Arayathanitkul, 2010) also revealed that many students tried to learn the physics by solving problems without understanding the fundamental concepts of physics. Gok, (2015), Reddy & Panacharoensawad (2017) and Walde (2017) reported that many students who learn physics by solving problems do not learn the fundamental concepts of physics and increase the number of misunderstanding about the fundamental concepts and the general principles. In addition, they do not need to use multiple representations because they focus only on using formulas and finding a numerical result when solving problems. In fact, when solving physics problems, students are expected to recognize and learn the fundamental concepts and also use multiple representations (Theasy, Wiyanto, & Sujarwata, 2018). This situation has led to many misconceptions being created among students because physics teachers use traditional teaching methods instead of active learning approaches (Abdjul, Ntobuo, & Payu, 2019; Bao & Koeing, 2019; Batlolona, Singerin, & Diantoro, 2019; Nisa, Jatmiko, & Koestiari, 2018). Therefore, this study used peer discussion approach to keep students active throughout the class, learning fundamental concepts and understanding multiple representations.

Peer discussion (PD) is the practice of peer instruction based on the constructivist approach (Gok, 2015; Lasry, Charles, Whitaker, 2016). The peer instruction can be determined as an "interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material" (Mazur & Watkins, 2010). Mazur's (1997) peer instruction technique utilizes multiple-choice questions to aid in the comprehension of fundamental concepts and identification of student misconceptions, as outlined by Gok (2015). Isomorphic problems were used for multiple-choice questions. Isomorphic problems were similar questions in terms of structure and content. Some researcher (Ivanjek, Susac, Planinic, Andrasevic, & Milin-Sipus, 2016; Reay, Li, & Bao, 2008) defined isomorphic problem as question sequences and/or parallel question. Peer discussion and isomorphic problems were combined to learn fundamental concepts and interpret the multiple representations of the high school students. The combination of peer discussion and isomorphic problems was applied to kinematics (motion along a straight line, motion in two or three dimensions), Newton's Laws of Motion, the application of Newton's Laws. A large number of multiple representations (free-body diagram, graph, etc.) are used to describe these topics. Also, in this section, students have the most common misconceptions ("velocity", "speed", "position", "displacement", "average velocity", "instantaneous velocity", "average acceleration", "instantaneous acceleration", "acceleration due to gravity", "force", "net force", "friction force", "mass and weight", "inertia", "equilibrium", etc.).

The combination of peer discussion and isomorphic problems (PD-IPs) consists of five steps. The first step is to give a short lecture and multiple-choice questions. The second step is to give students time to think about and report their answers. The third step is to evaluate and collect individual answers. The fourth step is to start peer discussion with isomorphic problems and re-evaluate the individual answers. In this step, students try to find a correct answer by critically analyzing the thinking behind different interpretations. The final step is to present the solution/discussion of multiple-choice questions. If the teacher deems it necessary, he/she re-initiates the discussion between the peer groups. The details of these steps have been described in the method.

Peer discussion has some advantages to both students and teachers (Antwi, Raheem, & Aboagye, 2016; Gok & Gok 2022; Woo, Rameli, & Kosnin, 2022). Students can learn concepts through questioning, correct misconceptions, and use multiple representations to solve physics problems through group discussion (Nielsen, Hansen-Nygård, & Stav, 2012). Students can share and change their ideas while peer discussion. Students can develop a positive attitude towards teaching when they share their thoughts and knowledge with their peers through discussion. Teachers can teach students the fundamental concepts and principles in a simple and applicable way. They can identify and correct students' misconceptions. They can teach students fundamental concepts and general principles through multiple representations by combining peer discussion with isomorphic problems (Millar & Manoharan, 2021; Tullis & Goldstone, 2020).

Many research (Abas, et al., 2022; Bauer, Biehler, & Lankeit, 2022; Tullis & Goldstone, 2020; Versteeg, van Blankenstein, Putter, & Steendijk, 2019) positively revealed the effects of peer instruction on students' conceptual understanding, problem solving, and reasoning, regardless of their background and gender, during physics instruction. Many studies have shown that peer instruction also enhances the development of students' affective (motivation, attitude, etc.) and psychomotor domains (Al-Hebaishi, 2017; Celik & Pektas, 2017; Gok, 2013; Gok, 2014; Mariati, Betty, & Sehat, 2017; Straw, Wicker, & Harper, 2021; Zang, Ding, & Mazur, 2017). However, the literature indicates that it is not used to teach kinematics and Newton's Laws of Motion through the combination of peer discussion and isomorphic problems. The research findings will fill the gap in the literature and guide teachers and researchers who will conduct research on this topic. They will also help students who have difficulty understanding and interpreting Newton's Laws of Motion and fundamental concepts and graphs of kinematics.

As mentioned earlier, the research has two dimensions. The first of these dimensions is learning the fundamental concepts and the other is understanding and interpreting the graphs. These components are extremely important for teaching physics. The use of graphs is very important for understanding, analyzing, and interpreting the fundamental concepts ("force", "acceleration", "velocity", etc.) in physics (Planinic, Ivanjek, & Susac, 2013; Planinic, Milin-Sipus, Katic, Susac, & Ivanjek, 2012). Beichner (1994) reported "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 revealed "graphs summarize large amounts of information while still allowing details to be resolved." Manurung, Mihardi, Rustaman, & Siregar (2018); Petrova, (2016), Theasy, Wiyanto, & Sujarwata (2018) pointed out that the ability to understand and interpret kinematics graphs is crucial in making students scientifically literate. In this context, students need to learn the general concepts of kinematics in order to interpret and draw kinematic graphs. Students also need to learn the fundamental concepts of Newton's Laws of Motion so that they can create free body diagrams and represent forces (Zavala, Tejeda, Barniol, & Beichner, 2017)

Several studies (Amin, et al., 2020; Antwi, Savelsbergh, & Eijkelhof, 2018; Ivanjek, et al., 2016; Maries & Singh, 2013; Vaara & Sasaki, 2019) have indicated that a significant number of students struggle with reading kinematic graphs, calculating and interpreting areas, interpreting transitions between kinematics graphs, and comprehending the meaning of slope. These studies also highlight difficulties in comprehending the fundamental concepts of kinematics and dynamics, differentiating between related concepts, and identifying and resolving conceptual confusions.

Students are expected to understand the fundamental concepts, determine the desired and given variables in the graphs, make a connection between the fundamental concepts and the graphs, state the direction of force, net force, acceleration etc., and explain the graphical and conceptual solution while learning kinematics and Newton's Laws of Motion using a combination peer discussion and isomorphic problems. Thus, the combination of peer discussion and isomorphic problems can help students understand fundamental concepts and graphs. In this context, the study sought answers to the following two research questions.

1) Does the combination of peer discussion and isomorphic problems affect high school students' understanding of kinematics graphs and Newton's Laws of Motion?
2) Are there differences between female students and male students' understanding of kinematics graphs and Newton's Laws of Motion in the groups?

METHOD

A quasi-experimental design was used for the study (two groups, pretest-posttest). Physics instruction was provided to high school students, who were divided into an experimental and a control group, using two different instructional approaches. The experimental group was taught using the peer discussion with isomorphic problems (PD-IPs) approach. The control group was taught using the traditional teaching method.

Participants

The study sample consisted of 67 11th grade high school students. High school education in Turkey lasts four years (from 9th to 12th grade) and is compulsory. The experimental group (EG) consisted of 34 students (16 females and 18 males) and the control group (CG) consisted of 33 students (14 females and 19 males).

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 nine weeks. (Classes lasted about 4 hours per week.) The main objective of the physics course was to familiarize the students with the definition and explanation of kinematics and Newton's Laws of Motion. An experienced and volunteer physics teacher was instructed by the researcher in the PD-IPs approach. The teacher taught the same content to both groups. Three isomorphic multiple-choice question based on graphical and conceptual tests were solved in one lesson. Some multiple-choice questions can be found in Appendix I.

The procedures of the PD-IPs approach, as shown in Figure 1, were as follows: a) The teacher gives short presentations to each class on fundamental concepts. b) The teacher shows three multiple-choice questions after each short presentation. The teacher usually uses standardized tests. The some standardized tests used were "Force Concept Inventory" (Hestenes, Wells, & Swackhamer, 1992), "Representational Variant of the Force Concept Inventory" (Nieminen, Savinainen, & Viiri, 2010), "Force & Motion Conceptual Evaluation" (Thornton & Sokoloff, 1998), "Mechanics Baseline Test" (Hestenes & Wells, 1992), "Test of Understanding Graphs in Kinematics" (Beichner, 1994), "Mechanics Diagnostic Test" (Halloun & Hestenes, 1985), except for pre/post-test questions. The textbooks (Mazur, 1997; Young & Freedman, 2008) for conceptual and graphical multiple-choice test questions were also used. c) Students are given time to think about each answer. They are not allowed to talk to each other. d) They report their individual answers. Flashcards ("red for A", "yellow for B", "green for C", "blue for D", and "white for E") are used during the voting process to report students' answers in this procedure. e) The teacher checks the correct answers (CA) of the students. If the number of correct answers is less than 30%, he/she explains the test question again and/or gives a brief explanation about the concept and/or graph. If the number of correct answers is above 70%, he/she explains the solution and then moves on to the new questions. f) When the number of correct answers reaches 30%-70%, he/she asks an isomorphic multiple-choice question with the same content as the previous task. The teacher initiates the solution to the isomorphic test question by having a whole-class group discussion. Students share their answers using the isomorphic test question in the discussion. After the group discussion, they share their individual answers again using the flashcard. The isomorphic test questions can be graded as easy and/or difficult depending on the students' performance, academic background, and subject content. g) Then the teacher checks the correct answers (CA) of the students. If the number of correct answers is less than 30%, the teacher asks students to discuss the same question with their classmates one last time and then asks them to show the answer to the question. The teacher gives general feedback to the students by explaining the correct answer in the last step.

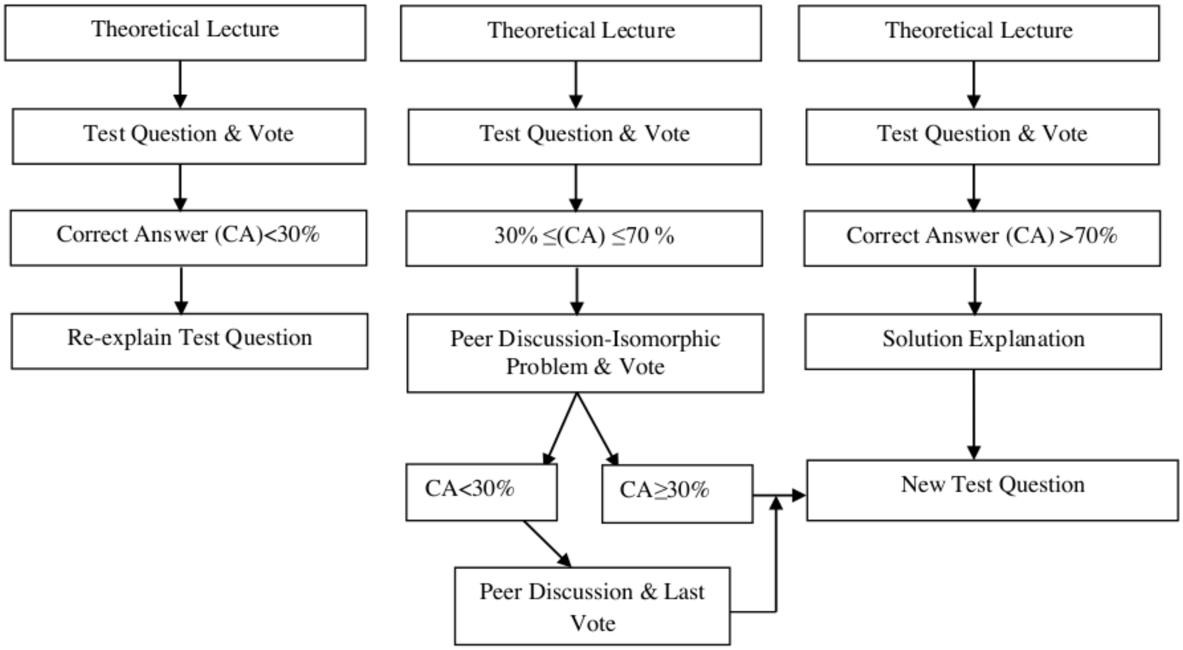

Figure 1. The procedure of PD-IPs approach

The procedure of the traditional teaching method was as follows: The teacher gives short presentations to each class on fundamental concepts. After the presentations, he/she asks three multiple-choice questions. Students are given time to think about each answer. They are not allowed to talk to each other. They turn in their individual answers using flashcards. Finally, the teacher evaluates the students' answers.

Data Collection

The multiple-choice questions used in the study were selected from the Mechanic Baseline Test (MBT), the Test of Understanding Graphs in Kinematics (TUG -K), and the Force Concept Inventory (FCI). The Force-Motion Achievement Test (FMAT), consisting of 25 questions, was administered to the groups as a pretest and posttest. The FMAT test questions were divided into two sections. The first section included 11 multiple-choice graphical questions (FMAT-G) and the second section included 14 multiple-choice conceptual questions (FMAT-C). The distribution of the test questions can be found in Appendix II.

The difficulty indexes of the selected test questions showed that three test questions were very easy (item statistics<-2.00), three test questions were very difficult (item statistics > 2.00), and the rest of the test questions were moderately difficult (-2.00 to 2.00). The discrimination indexes of the test questions showed that four test questions had a very high index (> 1.7), fourteen test questions had a high index (1.35-1.69), ten test questions had a moderate index (0.35-1.34), and one question had a low index (0.35-0.64). More detailed statistical analyzes of the results of TUG-K (Beichner, 1994), FCI (Hestenes, Wells, & Swackhamer, 1992), and MBT (Hestenes & Wells, 1992) can be found in the original papers.

Data Analysis

Student responses related to the pretest and posttest of the FMAT were analyzed using SPSS 21 using descriptive statistics, fractional gains (g), and analysis of variance (ANOVA). Hake's formula was used to calculate fractional gains. Hake (1998) defined three specific ranges ("high gain; g≥0.7," "medium gain; 0.7=g≥0.3," and "low gain; g < 0.3") for fractional gains.

After determining that the difference between the pretest means of the experimental and control groups was not significant (p>0.05), ANOVA was conducted to test the main effect of treatment on the posttest means of the experimental and control groups. FMAT results to determine the effects of the approaches used were analyzed using non-parametric statistics (Mann-Whitney U test) to determine the gains of female and male students in the EG and CG.

RESULT AND DISCUSSION

Descriptive statistics of the groups' pretest results indicated that the results were similar at baseline (Table 1). Analysis of variance (ANOVA) showed that the pretest results of the groups were not statistically significantly different, F(1-65)=0.08, p>0.05. while the posttest results of the groups were statistically significantly different, F(1-65)=116.81, p<0.05. It was calculated that the experimental group had a high gain (g=0.78) and the control group had a medium gain (g=0.50). The results showed that the combination of group discussion and isomorphic problems has a positive effect on the understanding of fundamental concepts and graphs among students in the experimental group.

Table 1. The FMAT scores of the students

			Pretest		Posttest		Gain
Group		N	M	S.D.	M	S.D.	g
Female	EG	16	2.06	0.85	17.06	1.29	0.65
	CG	14	2.00	1.57	12.21	0.70	0.44
Male	EG	18	2.33	1.08	22.56	1.04	0.89
	CG	19	2.47	0.61	14.74	0.87	0.54
Total	EG	34	2.21	0.98	19.97	3.00	0.78
	CG	33	2.27	1.13	13.67	1.49	0.50

Note: M: Mean; SD: Standard Deviation

Figure 2 shows the differences between the PD-IPs approach and traditional teaching method after and before the use of FMAT.

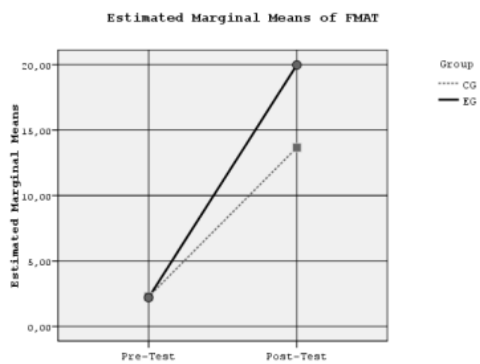

Figure 2. The differences between the groups' pretest and posttest scores

Figure 3 shows the gender differences between the PD-IPs approach and traditional teaching method after and before the use of FMAT.

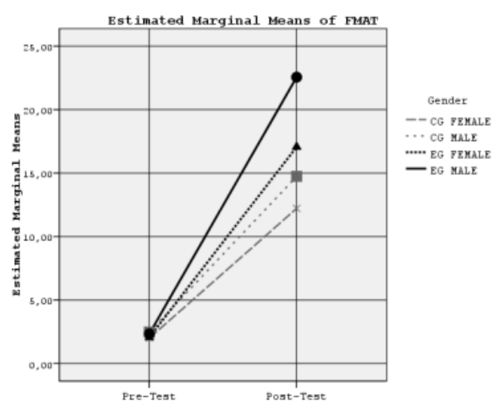

Figure 3. The differences between the female and male students' scores in the groups

The figure shows that the gains of female and male students in the EG were higher than the gains of female and male students in the CG. The results revealed that the PD-IPs approach is more effective than the traditional teaching method.

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 shown in Table 2 and Table 3. There was no statistically significant difference between the pretest scores of female students ($U=96.00$, $p>0.05$) and the pretest scores of male students ($U=153.50$, $p>0.05$) in the groups. But there was a statistically significant difference between the posttest scores of female students ($U=0.00$, $p<0.05$) and male students' posttest scores ($U=0.00$, $p<0.05$) in favor of EG.

Table 2. The female and male students' FMAT pretest scores

		Pretest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	16.50	264.00	96.00	0.49
	CG	14	14.36	201.00		
Male	EG	18	18.03	324.50	153.50	0.56
	CG	19	19.92	378.50		

Table 3. The female and male students' FMAT posttest scores

		Posttest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	22.50	360.00	0.00	0.00
	CG	14	7.50	105.00		
Male	EG	18	28.50	513.00	0.00	0.00
	CG	19	10.00	190.00		

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

When analyzing the FMAT based on the test questions, it was possible to examine the FMAT questions in two categories. These categories were graph questions (FMAT-G) and concept questions (FMAT-C). The FMAT-G consists of 11 test questions, while the FMAT-C consists of 14 test questions. The results of the identified categories were analyzed in detail. Table 4 shows the descriptive statistics related to the results of the FMAT-G and the fractional gain of the students in the groups.

Table 4. Descriptive statics of the groups' FMAT-G scores

			Pretest		Posttest		Gain
Group		N	M	SD	M	SD	g
Female	EG	16	1.13	0.81	7.50	1.41	0.65
	CG	14	1.14	0.86	4.93	1.33	0.38
Male	EG	18	0.94	0.64	10.27	0.96	0.93
	CG	19	1.11	0.81	6.89	1.59	0.58
Total	EG	34	1.03	0.72	8.97	1.83	0.80
	CG	33	1.12	0.82	6.06	1.77	0.50

Figure 4 shows the differences between the approaches used and gender after and before the application of FMAT-G. Analysis of variance (ANOVA) showed that the pretest results of the groups were not statistically significantly different, $F(1\text{-}65)=0.24$, $p>0.05$, whereas the posttest scores of the groups differed statistically significantly, $F(1\text{-}65)=43.72$, $p<0.05$, in favor of EG.

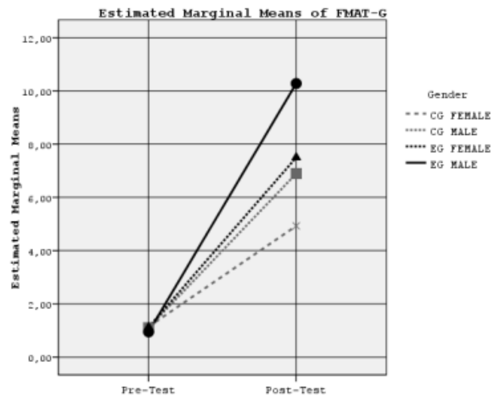

Figure 4. The differences between the students' FMAT-G pretest and posttest scores

When comparing the students' scores, the pretest scores of the students in the groups appeared to be similar, while the posttest scores of the students in the EG were higher than the posttest scores of the students in the CG. It was calculated that the fractional gains of female and male students in the EG were "medium" and "high", respectively. In the CG, the fractional gains of female and male students were "medium."

Figure 5 shows the distribution of the number of correct answers of students in relation to the FMAT-G. The results indicated that the number of correct answers of students in the EG was higher than the number of correct answers of 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.

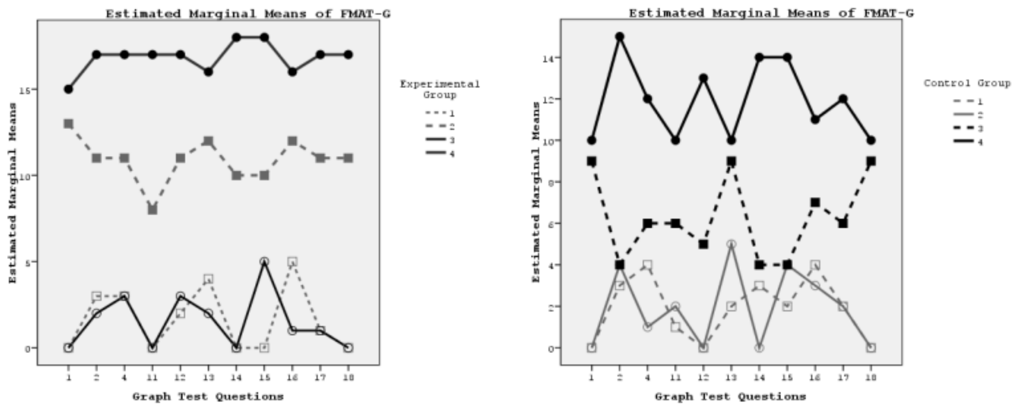

Figure 5. The number of correct answers given by students in the groups according to the FMAT-G test questions (1 & 3 female pre/posttest; 2 & 4 male pre/posttest)

In the general analysis of response rates to the test questions, the student response rate to the EG and CG was calculated to be 72% and 42% for the FMAT-G, respectively. In terms of gender, the response rate of female and male students on the EG was calculated as 58% and 85%, respectively, and the response rate of female and male students on the CG was also calculated as 31% and 53%, respectively.

Some conclusions from the test questions can be explained as follows: Students were asked to determine the maximum displacement from the velocity-time graph. The response rate (72%) of students to the EG was higher than the response rate (39%) of students to the CG. The response rate (94%) of male students on the EG was quite high. Similarly, the response rate of female students (50%) on the EG was higher than the response rate of female students (36%) on the CG for this test question. The academic performance of students in the experimental group in interpreting the velocity-time graph and understanding the selection of another corresponding graph was higher than the academic performance of students in the control group. Understanding the velocity-time and acceleration-time graphs was more difficult for the control group students than understanding the position-time graphs. When interpreting the slope of the graph and calculating the area under the graph, the students in the experimental group performed better than the students in the control group. In addition, the students in the experimental group could more easily translate the knowledge they had acquired into graphs and interpret the graphs. The results showed that the students of EG and CG should have mathematical processing skills to interpret and solve graphs.

The Mann-Whitney U test was used to compare FMAT-G pretest and posttest scores of students in the groups. The FMAT-G results are shown in Table 5 and Table 6. There was no statistically significant difference between the pretest scores of female students ($U=110.00$, $p>0.05$) and the pretest scores of male students ($U=155.00$, $p>0.05$) in the groups. But there was a statistically significant difference between the posttest scores of female students ($U=19.00$, $p<0.05$) and male students' posttest scores ($U=11.00$, $p<0.05$) in favor of EG.

Table 5. The female and male students' FMAT-G pretest scores

		Pretest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	15.63	250.00	110.00	0.93
	CG	14	15.36	215.00		
Male	EG	18	18.11	326.00	155.00	0.59
	CG	19	19.84	377.00		

Table 6. The female and male students' FMAT-G posttest scores

		Posttest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	21.31	341.00	19.00	0.00
	CG	14	8.86	124.00		
Male	EG	18	27.89	502.00	11.00	0.00
	CG	19	10.58	201.00		

Table 7 shows the descriptive statistics related to FMAT-C scores and fractional gains of students in the groups.

Table 7. Descriptive statics of the groups' FMAT-C scores

			Pretest		Posttest		Gain
Group		N	M	SD	M	SD	g
Female	EG	16	0.94	0.85	9.56	1.15	0.66
	CG	14	0.86	0.95	7.23	1.68	0.48
Male	EG	18	1.16	1.14	12.28	0.89	0.87
	CG	19	1.37	0.96	7.84	1.17	0.51
Total	EG	34	1.17	1.03	11.00	1.71	0.77
	CG	33	1.15	0.97	7.61	1.41	0.50

Figure 6 shows the differences between the approaches used and gender after and before using the FMAT-C. Analysis of variance (ANOVA) showed that the pretest scores of the groups were not statistically significant difference, $F(1\text{-}65)=0.10$, $p>0.05$, while whereas the posttest scores of the groups differed statistically significantly, $F(1\text{-}65)=78.42$, $p<0.05$, in favor of EG.

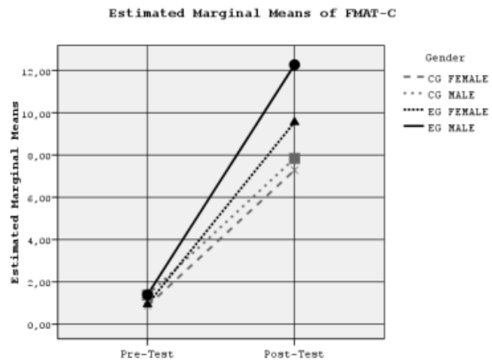

Figure 6. The differences between the students' FMAT-C pretest and posttest scores

The results of the score comparison showed that the pretest scores of the students in both the experimental group and control group were similar. However, the posttest scores of the students in the EG were higher than those of the students in the CG. Upon calculation, it was determined that the fractional gains of male students in the EG were "high", while female students in the same group achieved "medium" gains. In contrast, both male and female students in the CG achieved "medium" fractional gains. Figure 7 displays the distributions of the number of correct answers given by students in relation to the FMAT-C.

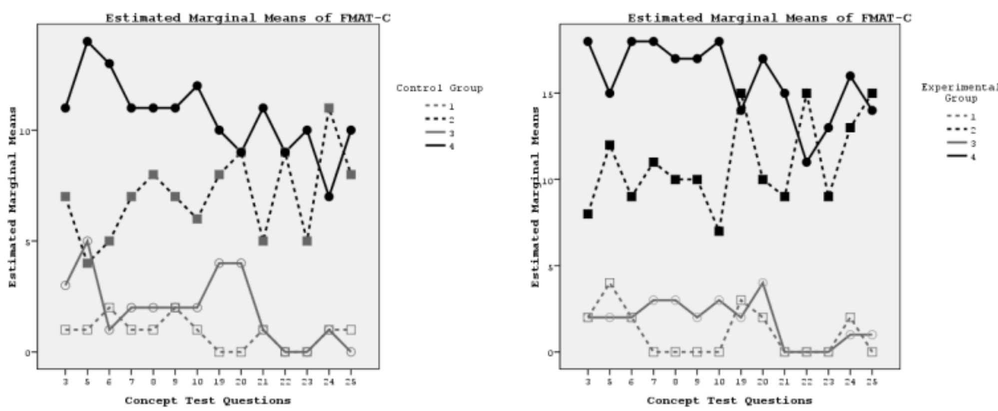

Figure 7. The number of correct answers given by students in the groups according to the FMAT-C test questions (1 & 3 female pre/posttest; 2 & 4 male pre/posttest)

Upon analyzing the response rates of test questions in accordance with FMAT-C, it was found that students in the experimental group had a response rate of 70%, while students in the control group had a response rate of 46%. When analyzed by gender, the response rate of female and male students in the EG was calculated as 62% and 78%, respectively. The response rate of female and male students in the CG was also found to be 46%. In regards to the application of general principles and kinds of forces, the response rate of students in the experimental group (74%) was higher than that of the control group (51%).

The Mann-Whitney U test was utilized to compare the FMAT-C pretest and posttest scores of students in both the experimental and control groups. The results of the FMAT-C can be found in Tables 8 and 9. The pretest scores of both female students ($U=103.50$, $p>0.05$) and male students ($U=166.00$, $p>0.05$) in the groups showed no statistically significant differences. However, there was a significant difference found between the posttest scores of female students ($U=30.00$, $p<0.05$) and male students ($U=0.00$, $p<0.05$), with the results favoring the experimental group.

Table 8. The female and male students' FMAT-C pretest scores

		Pretest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	16.03	256.50	103.50	0.71
	CG	14	14.89	208.50		
Male	EG	18	18.72	337.00	166.00	0.87
	CG	19	19.26	366.00		

Table 9. The female and male students' FMAT-C posttest scores

		Posttest				
Gender	Group	N	MR	SR	U	p
Female	EG	16	20.63	330.00	30.00	0.00
	CG	14	9.64	135.00		
Male	EG	18	28.50	513.00	0.00	0.00
	CG	19	10.00	190.00		

CONCLUSION

The research findings indicate that the peer discussion with isomorphic problems (PD-IPs) approach had a more positive impact on students' understanding of kinematics graphs and the fundamental concepts of Newton's Laws of Motion than the traditional teaching method. The PD-IPs approach facilitated students' comprehension of the fundamental graphs and concepts by allowing them to engage in constructive discussions with their peers. As a result, students were more likely to participate actively in class, learn graphs more effectively, and reinforce their understanding of the concepts. During peer discussions, students were more likely to provide correct answers to multiple-choice questions, indicating that the PD-IPs approach improved their problem-solving skills. Peer discussions also encouraged students to explore different perspectives and problem-solving approaches, and to be receptive to different explanations. Additionally, timely feedback provided after peer discussions enabled students to deepen their understanding of the fundamental concepts.

Based on classroom observations during the study, it can be inferred that the PD-IPs approach not only contributed to students' cognitive success but also positively affected their affective domains, such as attention, confidence, and motivation. The results of several previous studies (Gok & Gok, 2022; Haratua & Sirait, 2016; Nielsen, Hansen, & Stav, 2016; Sayer, Marhman, & Singh, 2016; Vickrey, Rosploch, Rahmanian, Pilarz, & Stains, 2015; Wang & Murota, 2016; Woo et al., 2022; Zhang et al., 2017) support the findings of the present study, which suggest that the PD-IPs approach is more effective than the traditional teaching method in improving students' conceptual understanding and interpretation of multiple representations. The research also revealed that isomorphic multiple-choice questions played a crucial role in identifying misconceptions and resolving existing problems among students. Previous studies by Kjolsing & Einde (2016), Michinov, Morice, & Ferriéres (2015), Millar & Manoharan (2021), and Savinainen, Nieminen, Makynen, & Viiri (2013) have emphasized the importance of isomorphic questions in enhancing students' conceptual understanding and use of multiple representations, such as free-body diagrams, verbal and graphical representations, among others. In terms of gender, the results showed that the PD-IPs approach had a greater positive impact on the academic performance of male students than female students. This finding is consistent with the results of previous studies by Bektasli & White (2012), Gok & Gok (2022), and Gok (2014).

Further research is necessary to assess the long-term retention rates and gains in conceptual learning and graph comprehension using the PD-IPs approach. Based on the findings of the current study, physics instructors can consider utilizing the peer discussion with isomorphic problems approach to teach fundamental concepts and multiple representations. Moreover, implementing the PD-IPs approach is both feasible and straightforward for teachers.

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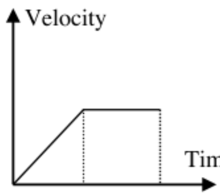
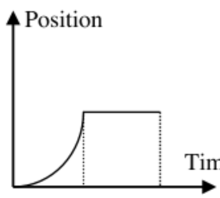
Appendix I

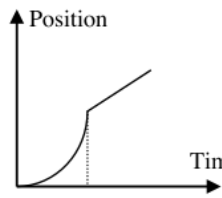
Sample Question 1:

Which of the following shows the position-time graph of an object whose velocity varies with time?

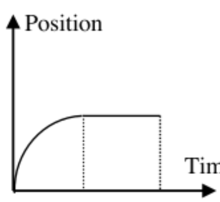


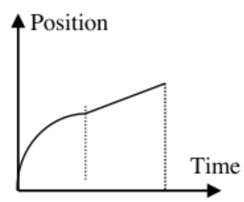
a) b)



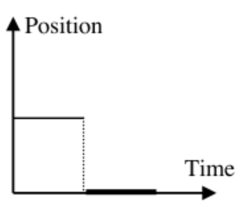


c) d)



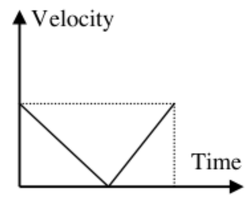


e)

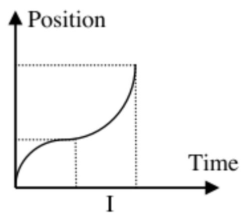


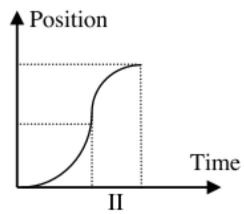
Isomorphic Test Question 1:

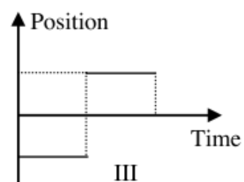
The velocity of a vehicle moving in a linear trajectory varies over time, as depicted in the given figure.



Which of the following graphs regarding the velocity-time graph of motion can be correct?







a) I b) II c) III
d) I and III e) II and III

Students' answer: Before and after the PD-IPs approach in the experimental group and traditional teaching in the control group

	Before PD-IPs	After PD-IPs	TT
	EG	EG	CG
Female	7 (44%)	9(56%)	6 (43%)
Male	11(61%)	14(78%)	9 (47%)
Total	18 (53%)	23(68%)	15(45%)

Sample Question II:

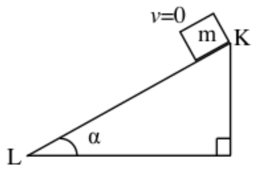


Figure-1

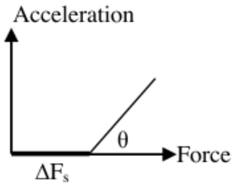
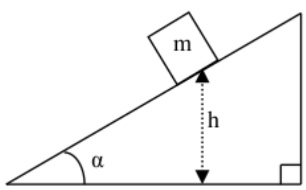


Figure-2

The object with mass m is released from point K on the inclined plane with friction as shown in Figure 1 and reaches point L. As a result, the acceleration-force graph of the object is shown in Figure 2. When the inclined plane makes an angle greater than α with the horizontal, what can be inferred about the values of ΔFs and θ on the acceleration-force graph if the same object is released from point K?

	ΔF_s	θ
a)	Decrease	Increase
b)	Increase	Decrease
c)	Decrease	Constant
d)	Increase	Increase
e)	Constant	Constant

Isomorphic Test Question 2:



An object of mass m rests on a frictional inclined plane at height h. Which of the following must be done for the object to move?

I. α constant, h increase
II. α increase
III. m increase

a) only I b) only II c) only III
d) I and II d) II and III

Students' answer: Before and after the PD-IPs approach in the experimental group and traditional teaching in the control group

	Before PD-IPs	After PD-IPs	TT
	EG	EG	CG
Female	8 (50%)	12(75%)	7 (50%)
Male	11(61%)	15(83%)	10 (53%)
Total	19 (56%)	27(79%)	17(52%)

Appendix 2.

The difficulty index, content, and response rate of the female and male students in the groups regarding FMAT-G and FMAT-C test questions

	DI	Content	FMAT-G				FMAT-C			
			EG-F	EG-M	CG-F	CG-M	EG-F	EG-M	CG-F	CG-M
1	MDI	Kinematics, Curvilinear Motion, Tangential Acceleration	81%	83%	64%	53%				
2	MDI	Kinematics, Curvilinear Motion, Normal Acceleration	50%	83%	7%	58%				
3	MDI	Specific Forces, Gravitational Free-Fall					38%	89%	435	42%
4	MDI	Kinematics, Curvilinear Motion, Normal Acceleration, General Principles, Second Law	50%	78%	14%	58%				
5	MDI	Kinematics, Curvilinear Motion, $a=v^2/r$, Second Law, Specific Forces, Friction					50%	72%	21%	47%
6	MDI	General Principles, Superposition Principle, Third Law					44%	89%	21%	63%
7	EDI	General Principles, Superposition Principle,					69%	83%	64%	47%
8	MDI	General Principles, Superposition Principle,					63%	78%	50%	47%
9	MDI	General Principles, Superposition Principle,					63%	83%	36%	47%
10	MDI	Specific Forces, Gravitational Free-Fall					44%	83%	36%	53%
11	HDI	Kinematics, Velocity-Time Graph	50%	94%	36%	42%				
12	MDI	Kinematics, Acceleration-Time Graph	56%	78%	36%	69%				
13	MDI	Kinematics, Position-Time Graph	50%	78%	50%	26%				
14	MDI	Kinematics, Position-Time Graph	63%	100%	7%	74%				
15	MDI	Kinematics, Velocity-Time Graph	63%	72%	14%	53%				
16	MDI	Kinematics, Acceleration-Time Graph	44%	83%	21%	42%				
17	MDI	A Kinematics Graph -Select Another Corresponding Graph	63%	89%	29%	53%				
18	MDI	A Kinematics Graph- Select Another Corresponding Graph	69%	94%	64%	53%				
19	EDI	Kinds of Force, Gravitation, Acceleration Independent of Weight					75%	67%	57%	32%
20	MDI	Kinds of Force, Gravitation, Acceleration Independent of Weight					50%	72%	64%	26%
21	HDI	Kinds of Force, Gravitation					56%	83%	29%	53%
22	MDI	Newton's Laws of Motion, Kinds of Force, Gravitation					94%	61%	64%	47%
23	HDI	Newton's Laws of Motion, Kinds of Force, Gravitation					56%	72%	36%	53%
24	EDI	Kinds of Force, Gravitation					69%	83%	71%	32%
25	MDI	Kinds of Force, Gravitation					94%	72%	50%	53%

Note: DI: Difficulty Index; E: Easy (EDI); M: Moderate (MDI); D: High (DDI); F: Female; M: Male

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