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VISUAL LEARNING ANALYTICS IN PEER INSTRUCTION: MAPPING STUDENTS' CONCEPTUAL TRANSITIONS IN KINEMATICS

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Abstract

Peer Instruction (PI) is widely known and most popular methods in physics. PI is an effective method for promoting student interaction and improving conceptual understanding in physics. However, instructors often lack real-time insights into students' thinking processes during PI. Guiding discussions effectively and addressing misconceptions became more challenging. This study examines how PI affects students' conceptual understanding and response transitions in kinematics, focusing on the visualization of response patterns using the Interactive Stratified Attribute Tracking (iSAT). The study involved 40 preservice science teachers and implemented eight conceptually rich multiple-choice questions (ConcepTests) adapted from Mazur's PI framework. Pre and post discussion responses were analyzed using descriptive statistics, normalized gain (N-Gain), paired sample t-test, and iSAT-based visualization. Results showed a significant increase in students' conceptual understanding after peer discussion ($t = 5.28$, $\rho < 0.001$), with a moderate mean N-Gain of 0.30 and a large effect size (Cohen's $d = 0.84$). Visual analysis using iSAT revealed important transition patterns such as correctly aligned and starburst on high gain questions, especially on non-graphic kinematics concepts. In contrast, questions involving motion graphs showed sliding and misaligned patterns, indicating persistent misconceptions and peer-driven response shifts toward incorrect choices. These findings suggest that while PI supports conceptual growth, it may inadvertently reinforce misconceptions in complex representational tasks. The integration of iSAT adds a valuable dimension to peer learning research by mapping students' transitions across discussion phases. Future research should explore instructional supports to reduce negative peer influence and strengthen understanding of graphical representations in physics.

Keywords: Active Learning; Kinematics; Peer Instruction; Physics Learning: Students' Answer Patterns; Visual Analytics

INTRODUCTION

Active learning has become increasingly important in physics education due to its capacity to engage students in constructing knowledge rather than passively receiving information (Chi, 2009; Chi & Wylie, 2014; Mazur, 1997; Michael, 2006; Von Korff et al., 2016; Waldrop, 2015). Among various active learning strategies, Peer Instruction (PI) has proven especially effective in promoting students' conceptual understanding by promoting discussion and reflection (Crouch & Mazur, 2001; Fagen et al., 2000, 2002; Lasry et al., 2008; Mazur, 1997; Miller et al., 2015).

PI, developed by Eric Mazur, involves a cycle of conceptual questioning (often via multiple-choice coneptual questions), individual responses, peer discussion, revoting the same conceptual question, and followed by an instructor-led explanation (Mazur, 1997, 2014). Peer Instruction (PI) is widely known and most popular methods in physics (Henderson & Dancy, 2009; Vickrey et al., 2015). PI is an effective method for promoting student interaction and improving conceptual understanding in physics. Numerous studies have confirmed its effectiveness in improving conceptual understanding, including kinematics concept (Pranata, 2025), mechanics (Gok, 2014) fluids mechanics (Wuttiprom, 2018), and relativitas khusus (Alvarez-Alvarado et al., 2019).

Despite its success, one key limitation of PI is the lack of real-time insight into students' conceptual thinking and their understanding. Instructors often find it challenging to identify how students' understanding evolves during the discussion process or to detect which misconceptions persist and resolved. While PI effectively addresses misconceptions and fosters conceptual change, it lacks tools to make students' learning transitions explicitly visible (Bicheng et al., 2023; Majumdar & Iyer, 2016). This limits instructors' ability to provide timely scaffolding or targeted feedback and to explore conceptual dynamics of their students.

To address this gap, Visual Learning Analytics offers a promising solution. Visualization tool and analysis provides graphical representations of data, helping educators and researchers map how student thinking evolves. In the context of PI, visualization tool and analysis can be used to visualize transitions from incorrect to correct answers (and vice versa), track persistence of misconceptions, identify prevalent patterns of conceptual change across a cohort.

One of the tools that compatible with PI procedures is Interactive Stratified Attribute Tracking (iSAT) (Majumdar & Iyer, 2016). iSAT enables educators to track answer transitions across phases (e.g., before and after peer discussion), offering clear visual insight into how students' conceptions shift—either individually or as a group.

This study explores the use of Visual Learning Analytics (Interactive Stratified Attribute Tracking or iSAT) to map students' conceptual transitions during PI in learning physics. The study was conducted in a Basic Physics course involving pre-service science teachers. Combination of Active Learning through PI with Visual Learning Analytics through iSAT, offering a novel way to track and understand how students' conceptions evolve during physics learning, especially on kinematics.

Based on this context, the study addresses the following research questions:

1) How do students' conceptual responses change before and after peer discussion?
2) What patterns of conceptual transition emerge during Peer Instruction in Physics Learning?
3) How can visual analytics tools represent these transitions?

METHOD

This study is the second phase of a research project investigating Peer Instrution (PI) in physics learning, especially on kinematics. The first phase used descriptive quantitative methods to explore students' concept understanding of kinematics in peer instruction learning and to improve students' understanding (Pranata, 2024). The second phase (reported in this study) foceses on the visual exploration of response transition patterns using Interactive Stratified Attribute Tracking (iSAT).

The study involved 40 pre-science teachers enrolled in basic physics course. All participants took part in the learning and assessment activities. Concept inventory or conceptual multiple-choice questions given at key points (before discussion and after discussion). Mazur referred to these conceptual questions as ConcepTest. In this study, a total of eight conceptests on kinematics were adapted and translated from Mazur's book on peer instruction (Mazur, 1997, 2014). Students' responses before and after discussion were analyzed to examine the improvement in understanding and the pattern of change in students' responses.

Data analysis was conducted in several stages. First, a descriptive analysis was performed based on correct answers and total scores. Student responses were scored using a binary system: correct answers were assigned a score of 1, while incorrect or unanswered questions received a score of 0. Based on these results, Normalized Gain (N-Gain) scores were calculated for. N-Gain calculations included the difference between before and after discussion scores as defined by the equation (Hake, 1998).

$$N - Gain = \frac{After\ Discussion\ score - Before\ Discussion\ score}{Maximum\ score - Before\ Discussion\ score}$$

The analysis of N-Gain was conducted at for each question item and individual students to highlight variations in learning outcomes across questions and among students.

Second, statistical analysis was performed to compare before and after discussion scores. either a paired samples t-test or the Wilcoxon signed-rank test was conducted, depending on the distribution of the data. The paired sample t-test was used for normally distributed data, while the Wilcoxon signed rank test was used for non-normally distributed data (Goss-Sampson, 2024; Morgan et al., 2004). These procedures, as established in the first phase of the study (Pranata, 2024), are briefly reiterated here to provide context and continuity with the subsequent visual analysis.

Third, students' response transitions were analyzed using a visual analysis tool called Interactive Stratified Attribute Tracking or iSAT. This tool was developed by a previous researcher and is freely available online for educational and research purposes (Majumdar & Iyer, 2016). This analysis is important to understand how peer influence plays a role in the learning and testing process (Mazur, 1997, 2014). Majumdar & Iyer (2016) define seven transition patterns in peer instruction (PI) activities to help instructors analyze student responses across the voting phases (Table 1).

Table 1. Pattern Transition

Pattern	What It Means
Aligned	Students stay in the same answer group across all phases. If correct, it shows strong understanding. If incorrect, it may show a lasting misconception.
Starburst	Students move from one incorrect answer to several better (often correct) answers after discussion. This shows learning is happening.
Slide	Students go from a correct answer to an incorrect one. This shows confusion or a possible misunderstanding after discussion.
Return*	Students change their answer, then go back to their original answer. This shows uncertainty or inconsistency in their thinking.
Switching	Students change between different wrong answers. They are engaged but not yet understanding the concept correctly.
Attractor	Many students move to the same answer after discussion. This could mean either strong agreement or a shared misconception.
Void	No students move between certain answer choices. This might show that some misconceptions were completely cleared—or that some options were never chosen.

*Note: The Return pattern requires three answer phases of response data. As this study collected at only two phases (before and after discussion), this pattern is not included in analysis.

The identified transition patterns of the students' responses are analyzed for each ConcepTest question. The analysis was supported by visualization generated using iSAT tool, which enabled a clearer interpretation of students thinking and discussion outcomes.

FINDINGS AND DISCUSSION

Conceptual Understanding Before and After Discussion

The descriptive statistic of students' answers before and after the discussion is shown in Table 2.

Table 2. Descriptive Statistics Results

Before/After Discussion	Mean	Min	Max	Std. Deviation	Skewness		Kurtosis	
					Statistic	Std. Error	Statistic	Std. Error
Before	2.13	0	5	1.27	0.39	0.37	-0.51	0.73
After	3.88	1	8	1.74	0.32	0.37	0.4	0.73

The data in Table 2 show that the average score increased from 2.13 (before discussion) to 3.88 (after discussion) out of a maximum score of 8. These results indicate an overall improvement in students' conceptual understanding after peer discussion.

To assess the extent of this improvement, N-Gain scores were calculated for on each question and each individual student. The results showed an overall moderate improvement in conceptual understanding with a normalized gain (N-Gain) score of 0.30. N-Gain scores ranged from -0.07 to 0.80 for each question, as shown in (Figure 1) and from -1.33 to 1.00 for each student (Figure 2).

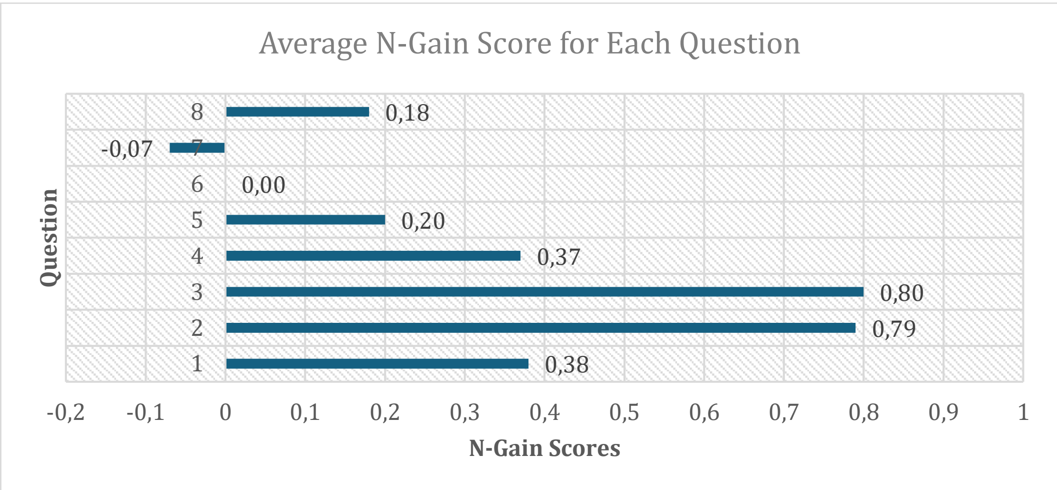


Figure 1. Average N-Gain Score for Each Question

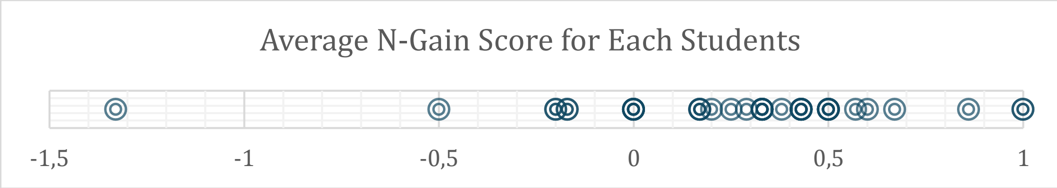


Figure 2. Average N-Gain Score for Each Students

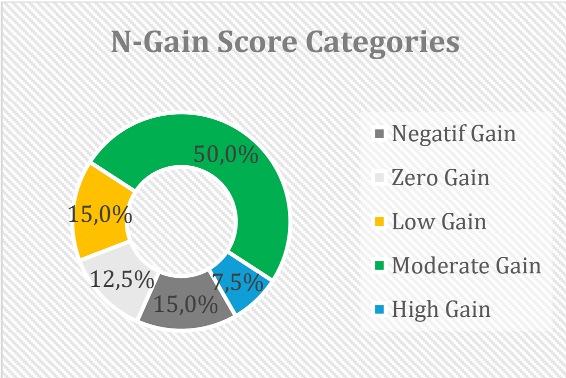


Figure 3. Student Distribution Based on N-Gain Categories

Based on the N-Gain score for each question (Figure 1), the eight questions were divided into several categories of improvement based on the categories summarized by Hake (1998). First, there were two questions with improved concept understanding in the high category with N-Gain scores greater than 0.7, namely the second question on the concept of distance and displacement (0.79) and the third question on comparing two horizontal motions (0.80). Second, there were two questions with an increase in the moderate category with N-gain scores greater than 0.3 and less than 0.7, namely the first question on constructing motion graphs from verbal descriptions (0.38) and the fourth question on free fall motion (0.37). Third, the other four questions with score improvement were classified as low (N-gain scores less than 3), equal to zero, and negative.

After reviewing the characteristics of the questions, 3 of the 8 questions are motion graphs. The first question constructs a position versus time graph from a verbal description, the sixth and seventh questions involve motion interpretation of the position versus time graph. By comparing the average N-gain between questions with and without graphs, it was found that the conceptual score increase without graphs was classified as moderate with an N-gain of 0.44, and the conceptual score increase with graphs was classified as low with an N-gain of 0.10. Thus, it can be concluded that PI learning can support conceptual improvement in kinematics. but students still have difficulty with kinematics concepts related to graphs, especially interpreting motion graphs. Previous studies also confirm that the difficulty students often have in kinematics material is understanding motion graphs (Bollen et al., 2016; Ivanjek et al., 2016; Zavala et al., 2017).

Based on the data in Figure 2, most students have a positive score gain, meaning that they can answer questions better after the discussion. Some students even have an N-Gain of 1, which means that the student can answer all questions correctly after the discussion. However, there are students with N-Gain equal to zero and negative. This data can be further explained by looking at Figure 3. Only 7.5% of the students with score improvement were found in the high category. There were 15% of students with score improvement in the low category and 50% in the moderate category. However, 12.5% of the students showed no improvement (zero gain) and 15% showed negative values. The negative value of N-gain indicates that the number of correct answers is lower after the discussion. This condition is interesting to study further.

Then, the conceptual gain was confirmed by comparing the average before and after the discussion using the paired samples t-test. The results are shown in Table 3.

Table 3. Paired Sample T-test

t	df	ρ	Cohen's d	SE Cohen's d
5.28	39	< 0.001	0.84	0.25

The test results show that there is a significant difference in the scores before and after the discussion ($t = 5.28, \rho =< 0.001$) with an effect size in the high category ($d > 0.8$) (Cohen, 1988). These results suggest that PI can improve students' concept understanding, especially in kinematics material. However, the understanding of the kinematics graph still needs attention.

Answer Patterns Transition

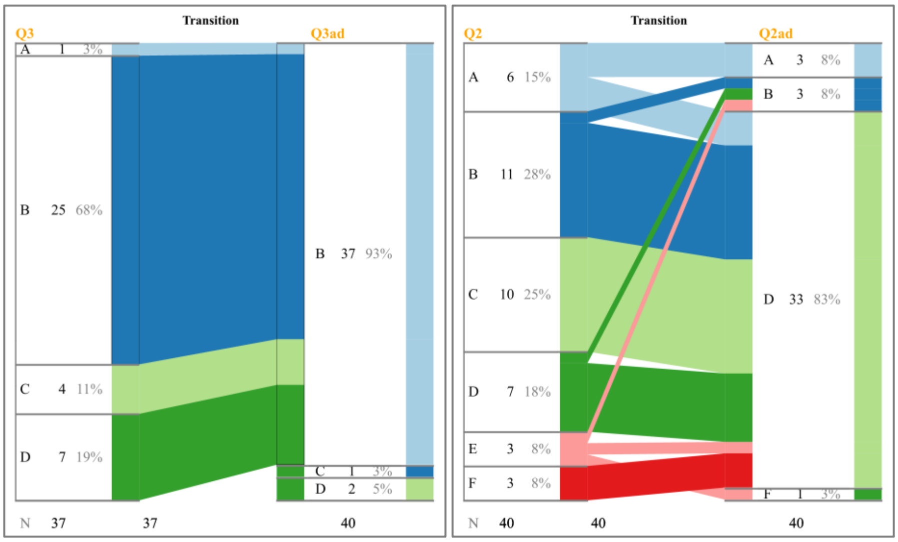
The transition patterns of the students' responses can be found using Interactive Stratified Attribute Tracking or iSAT. The results of the pattern mapping are shown in Table 4. The visualization of the transition pattern is shown in Figure 4 and subsequent figures.

Table 4. Answer Patterns Transition*

Question Number	Aligned		Starburst	Slide	Switching	Attractor	Void
	Correct	Incorrect					
Q1	✓ (8/8)	✓ (5/16)	✓			✓	✓
Q2	✓ (6/7)	✓ (3/6)	✓	✓	✓		✓
Q3	✓ (25/25)	✓ (2/10)	✓				✓
Q4	✓ (5/10)	✓ (9/21)	✓	✓	✓	✓	✓
Q5	✓ (10/15)	✓ (10/13)	✓	✓	✓	✓	✓
Q6		✓ (17/22)		✓	✓	✓	✓
Q7	✓ (4/12)	✓ (12/21)		✓	✓	✓	✓
Q8	✓ (3/6)	✓ (8/18)	✓	✓	✓	✓	✓
Total	7	8	6	6	6	6	8

*Pattern Existence (Ratio)

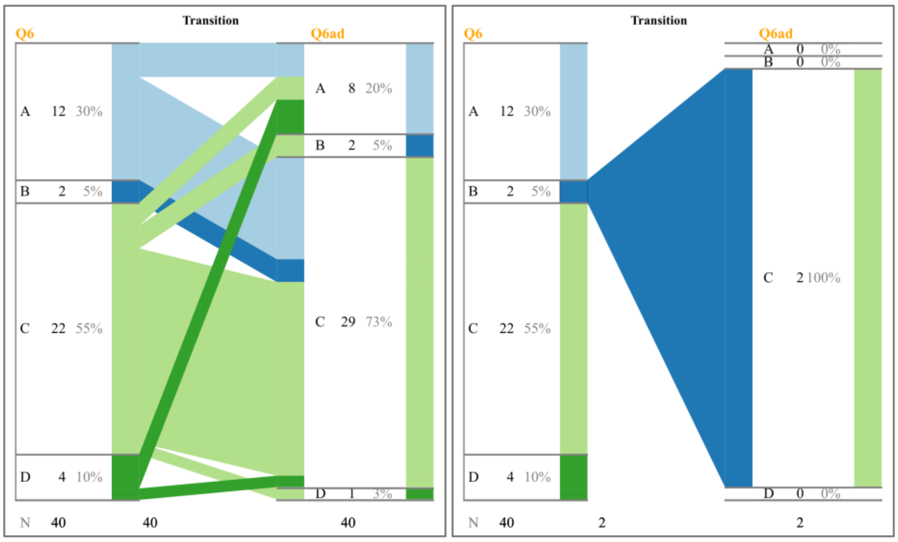
One key pattern identified is the **correctly aligned pattern**. This pattern is a desirable pattern in which students answer correctly before the discussion and continue to answer correctly after the discussion. This pattern also has the potential to influence other students who answered incorrectly before the discussion, producing what is known as **starburst pattern**. The most prominent starbursts were found in question #3 (correct choice B) and question #2 (correct choice D). The iSAT visualization for those reseults are shown in Figure 4, which represent group of students move to correct answer. This finding is consistent with the highest N-gain scores for question numbers 3 and 2. The **correctly aligned pattern** of some students is shown to influence the answers of other students (**starburst**).



(a) (b)

Figure 4. iSAT Result: (a) Question Number 3 and (b) Number 2

Interestingly, the **correctly aligned pattern** was found in all questions except question 6, which was about motion graphs. The visualization of the transition of students' answers is shown in Figure 5.

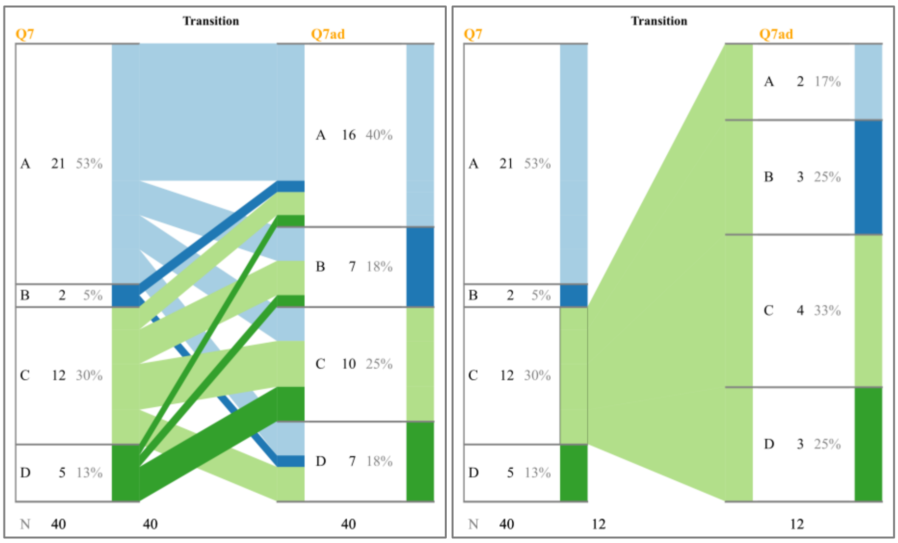


(a) (b)

Figure 5. iSAT Result for Question Number 6: (a) All students Answer Transition and (b) Slide

The correct answer for the question is B. None of the students were correct and remained correct after the discussion (Figure 5a). Although there were 2 students who answered correctly before the discussion (option B), both of them answered incorrectly after the discussion (option C), which triggered the presence of the slide pattern (Figure 5b). Consistent with this condition, no **starburst** was found.

Furthermore, the **incorrectly aligned pattern** was found in all questions. The higher the proportion of this pattern, the stronger the students' misconceptions. There are 17 students with this pattern in question number 6 (choice C) and 12 students in question number 7 (choice A). The visualization of iSAT question 6 is shown again in Figure 5. The visualization of iSAT question 7 is shown in Figure 6.



(a) (b)

Figure 6. iSAT Result for Question Number 7: (a) All students Answer Transition and (b) Slide

The presence of the **incorrectly aligned pattern** triggers other students to follow the answers according to the choices in that pattern. There are 12 additional students for question number 6, so there are 29 students who choose C, and 4 additional students for question number 7, so there are 16 students who choose A. In other words, the choice in incorrect aligned has great potential to be an **attractor** for other students. This pattern can even trigger slides where students initially answer correctly, but change their answers to incorrect, following students who have an **incorrectly aligned pattern**. For example, 2 students each for numbers 6 and 7.

CONCLUSION

This study shows that peer instruction (PI) can significantly improve students' conceptual understanding of kinematics, especially for concepts not related to motion graphs, as evidenced by moderate normalized gains (N-Gain = 0.30) and large effect sizes (Cohen's d = 0.84). The iSAT visualization showed positive transitions, such as a starburst pattern, indicating effective spread of correct reasoning among peers, especially on high N-gain questions. However, persistent misconceptions were found in graph-related questions, where misaligned and sliding patterns dominated, suggesting that students continue to struggle with interpreting motion graphs despite collaborative discussions. These findings highlight the dual nature of PI, which can enhance understanding or perpetuate misconceptions depending on peer influence and the cognitive demands of the question.

Future research should explore how targeted scaffolding strategies-such as structured prompts, concept-conflict questions, or instructor-led clarifications-may reduce the spread of misconceptions during peer instruction, especially in graph-based kinematics. In addition, incorporating multi-representations and real-time visual analytics such as iSAT in other physics domains may provide deeper insights into how students' conceptual transitions occur in collaborative environments. Longitudinal studies across different learning topics and student populations are also recommended.

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