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Beyond Clickers: Tracing Patterns in Students' Response through iSAT

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Abstract: Interactive Stratified Attribute Tracking (iSAT) diagram is a visual analytics tool for cohort analysis. Instructors can use it to visualize transitions of group of students during teaching-learning activities. In this paper we show how iSAT can be used to analyze clicker responses during a Peer Instruction (PI) activity. PI is an active learning strategy where instructor poses a deep conceptual multiple-choice question that the students have to first answer individually. It is followed by a peer discussion phase after which they re-vote their answer. Clickers are often used to collect those votes and histograms visualize the distribution of responses in the pre and post phases of voting. PI is analyzed by its learning gain across these phases. We show the use of iSAT to analyse clicker data and in real-time elaborate the transitions of participants' responses during various voting phases. Such transition patterns are neither available in multiple histograms of individual voting phase nor generated in real time to be visualized as a flow diagram. It is also cumbersome to analyze learning patterns for more than two phases of voting from any static diagram. We believe that interactive visual analytics gives the instructor the affordance of understanding the dynamics of the class during a PI session and thereby engage in informed planning for the next activity. We consider reported data from an Introduction to Computer Architecture course where PI was conducted as our working example. We regenerate the data and visualized it as an iSAT diagram. We further categorize the various transition patterns of PI clicker responses which emerge with the help of that example and classify them into *Aligned, Returns, Starburst, Slide, Attractor, Switching* and *Void*. We conclude by highlighting the power of iSAT for instructors to do cohort analysis in their teaching learning practice.

Keywords: iSAT, Active Learning, Peer Instruction, Learning Analytics, Cohort Analysis, Visual Analytics.

1. Introduction

Technology enabled active learning practices are transforming both in-class and online teaching-learning scenarios. Many of these active learning strategies can benefit from the availability of logged data. Learning analytics on the data logged during such activities can further help instructors to gain insights and reflect on their practice (Duval, 2011). We have developed a tool called Interactive Stratified Attribute Tracking (iSAT) for visual learning analytics. In this paper we focus on one such active learning strategy called Peer Instruction (PI) and show how iSAT can help instructors to trace transitions in answering patterns in a class. It assists the grouping of students into a cohort according to the transitions they follow and take informed instructional decisions based on it.

In PI (Mazur, 1997) (see Fig 1 for activity flow), students are encouraged in active learning through a deep conceptual multiple-choice question (MCQ) on the current topic on which they vote individually. This is followed by a discussion with the neighbor to justify their answer. Then they re-vote their choice on the basis of the discussion. For closure there is an instructor-led classroom discussion regarding the correct answer or clarifying alternate conceptions based on which the wrong options were designed.

Figure 1. Activity flow in a classic Peer Instruction (PI) activity

Clickers or similar personal response systems (PRS) are often used as a technology support to collect these responses from the students. Aggregate level statistics, like histograms of answer choices or percentage correct in each phase of voting is normally generated from that data and educational researchers analyze learning gain during such activities (Hake, 1998). The instructor can sense the success of the activity when majority of the class vote the correct option as their answer.

But such aggregate view doesn't reveal the underlying pattern of transition in students' response. The instructors remain unaware of critical information like what proportion of the class has switched options and gone from a correct to incorrect one, how many fail to answer correctly across phases and so on. Such information can be effectively used to further plan on the post PI activities.

We bridge this gap by utilizing Interactive Stratified Attribute Tracking (iSAT) Diagram to visualize those transition patterns. We have developed iSAT, a tool to visualize transitions of attribute values across phases. iSAT visualizes the distribution of each cohort in a phase as nodes and traces its transitions across phases as links. In context of PI, the voted answers to the MCQs are the attributes. We can stratify them according to the option answered or it's correctness and track across the voting phases during PI (see Fig 6 for example). Including iSAT in PI (activity flow as shown in Fig 2.) enables an instructor to trace various answering patterns across the activity, and identify the different cohorts of students based to it. Further instructional planning can be done to cater to such cohorts.

Figure 2. Introducing iSAT in PI activity

In section 2 we describe typical analytics done on PI response data with the help of a working example and then introduce iSAT to explain how it assists the instructors to visualize answering patterns in real time and analyze cohorts in section 3. We conclude by highlighting the power of iSAT to conduct analysis of a cohort transition and how it can be useful for online instructors.

2. Peer Instruction and its Learning Analytics

2.1 Peer Instruction

Eric Mazur first introduced PI in 1991 in an introductory physics courses for non-majors at Harvard University (Mazur, 1997) and early educational research were primarily done in the domain of Physics. The instructor initiates the activity by posing a deep conceptual multiple-choice question (Q1) on the topic of discussion that the students have to answer individually (see Fig 1 for activity flow). To facilitate students answering, instructors often use PRS like clickers or flashcards. Following that the students briefly discuss with their neighbor their answer and the reasoning about their choice. They re-vote after discussion ($Q1_{ad}$). For closure there is an instructor-led discussion. Instructor may choose to show the distribution of the answered choice after the first round of voting as a Histogram and then again update it after the second round of re-voting (see Fig 1. stage 2 and 5).

Smith et.al (2009) further modified the classic versions of PI for an undergraduate genetics course and introduced Isomorphic question (Q2) as a third phase of voting (see Fig 3). Isomorphic questions are essentially on the similar concept as Q1. Later, Porter et.al (2011) investigate the effectiveness of PI with isomorphic questions in the domain of Computer Science (CS) education. Researchers (Smith et.al 2009, Porter et.al 2011) analyzed the proportion of students who are correct with respect to the previous voting phase by using a Flow Chart (see for example Fig. 5a and Fig. 5b).

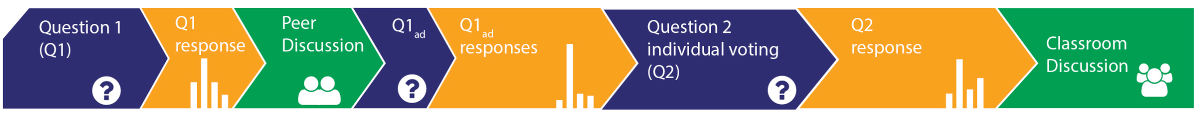


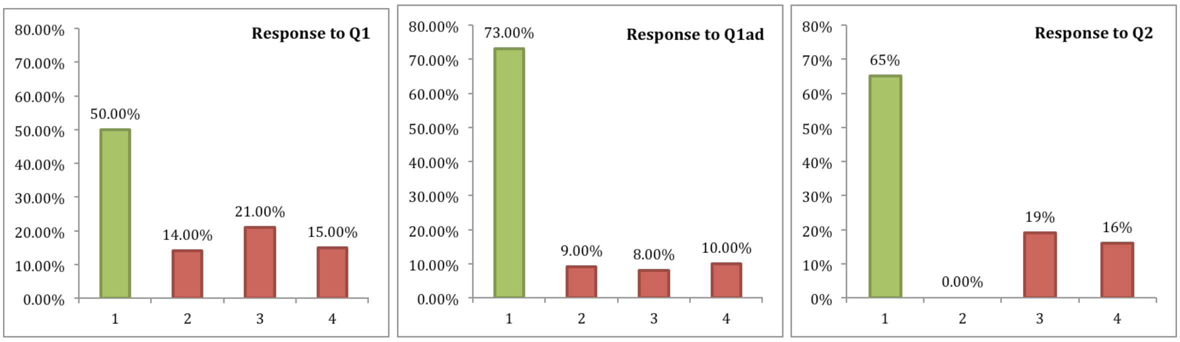
Figure 3. Modified PI activity flow with isomorphic questions (Q2)

2.2 Our working example and reconstructed dataset for learning analytics of PI

In order to explain the power of iSAT we reconstructed random students' response across three PI phases and matched the aggregate results from the Introduction to Computer Architecture (CArch) course as reported by Porter et.al (2011). In their reported study the implementation of PI had an isomorphic question. They present percentage of correct responses for all three phases of voting (Q1, $Q1_{ad}$ and Q2) as a bar chart and also provide the flow chart (tree diagram) of the students' response correctness over the isomorphic sequence. We reconstructed 300 clicker responses as answers to those three questions by 100 students. We considered there are 4 options in the MCQs and each option is linked to an alternate conception in the assumed topic and that the correct answer for both the question is option 1. An example of our generated data is: student #46, response on {Q1, $Q1_{ad}$, Q2} is {2,1,3}. It means the student was incorrect in the first phase of individual voting, and then he chose the correct answer during re-voting after peer discussion but was again wrong during voting for Q2.

We use the reported study just as an illustrative PI activity and to regenerate dataset of response. Using it as a working example we elaborate the aspects of PI response analytics in this section. Later we visualize the patterns through iSAT and elaborate the cohort analysis based on the regenerated dataset.

2.3 What does the Histogram and Flow Chart (Tree diagram) show regarding the students' response to PI question?



a b c

Figure 4. Reconstructed histograms based on data from Porter (2011)
a) Q1 response b) $Q1_{ad}$ response c) Q2 response

For our generated response set Fig 4 shows three histograms; first one (4a.) gives frequencies of voted options during the individual voting phase and second (4b.) for re-voting after discussion. For any classical PI implementation, similar histograms are generated based on the data logged by Clickers. They indicate frequency of students who voted in respective option categories. This helps in calculating proportion of students who are correct and incorrect in their responses. If there is linkage of alternate conceptions with incorrect response categories, e.g. options given in Force Concept Inventory in Physics (Hestenes, 1992), the histogram also informs the number of students who have a particular alternate conception during each phase of answering. The histogram corresponding to the re-voting (Fig. 4b) further indicates the final number of students who choose the correct option (73% for the CArch example), those who remain in the incorrect category after the PI intervention. Instructors often consider this histogram as an indicator to plan the closing discussion for the activity. They might emphasize on the specific concept in which most students still remain weak (as indicated by the highest number amongst the category of incorrect options) or even sense the success of the activity by noting the high frequency of the correct response.

In the extended version with isomorphic question Q2, the third Histogram (Fig. 4c) shows the distribution of the Q2 response. In our example of CArch course, there is a fall of 8% of the total students; those who responded correctly after PI re-voting (73% of students were correct) but failed to choose the correct option for the isomorphic question (65% of the students were correct). Other information that can be derived is none of the students voted option 2 as the answer and considering the three visualizations considered together, we see a decline in the frequency of option 2 as a student response (Q1- 14%, Q1ad - 9%, Q2 – 0%).

Smith et.al (2009) visualized PI responses with isomorphic question and the performance of the students across 3 sets of responses (Q1, $Q1_{ad}$ and Q2), with a Flow Chart that essentially has a tree structure (e.g. Fig 5). The relative percentages of correct and incorrect response with respect to the previous response are denoted as the left and right branch respectively. Porter et.al (2011) presented one more view where the absolute portion of correct and incorrect response was visualized. Figure 5 redraws the relative and absolute Flow Chart for the CArch data. It shows 76% of the students who were correct in both the phases of voting for Q1 are correct in Q2. This cohort is 33% of the total population (see Fig. 5b). Given such a Flow Chart diagram, an instructor can directly search the bottom left element in the tree to find the information regarding the proportion of student who voted consistently correct answers. Additionally that element is underlined for attention. Fig 3a also shows 68% of the students, who are initially wrong and later rectifies after the peer discussion, correctly answer Q2. This cohort is 20% of the total sample size (Fig 5b). It is highlighted in bold.

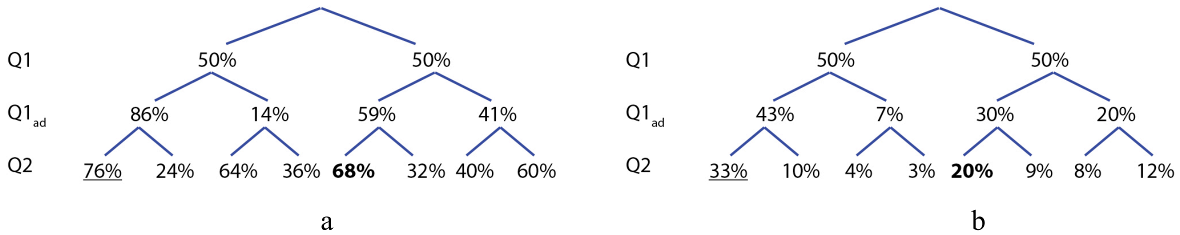


Figure 5. Flow charts (tree diagram) of correct (left) and incorrect (right) as reported in Porter (2011) a. relative percentage of previous response b. absolute percentage of total population size

2.4 Limitations of the histograms and flow chart visualization for PI response analysis.

The response data captured across multiple student activities contain details, but its granularity is lost if we consider only aggregate level count and plot it as a histogram for each phase. Such aggregation may limit the understanding of classroom trends by the instructor. Importantly separate histograms don't convey the pattern of change of students' response across different activities. The instructors do not know how many students are actually improving after the intervention. It doesn't highlight the cohort that re-votes an incorrect option or changes from a correct answer to an incorrect one. There is possibility of transition from one wrong option to another one during re-voting. Such cohorts are also missed in the aggregate level view of the class. For example the instructor doesn't get the picture of what part of the 21% of students who voted option 3 are present in the 73% cohort in the next phase.

The flow chart visualization of the correct and incorrect responses as a percentage of the previous question helps the researcher to analyze the activity in retrospect but might not be usable by the instructor for real-time feedback of the class. The Flow Chart also aggregates the trends for only correct or incorrect responses. For a multiple choice question designed to understand alternate conceptions, we loose the rich data of shifting conceptions once we process it only as correct or incorrect. The instructor loses the granularity to find how many people or what proportion of the 14% changed their answer from option 2 to option 3 during re-voting. Moreover any static diagram becomes cumbersome to read and interpret during an in-class activity when there are patterns for multiple attribute values. To overcome these limitations and assist an instructor in visual analytics of real-time response to understand students answering patterns, we have developed the iSAT tool.

3. iSAT as a tool for cohort analysis in PI

3.1 Visual Learning Analytics through iSAT

Technology enables gathering of data towards informed teaching-learning practices (Vickrey, 2015). Using visualizations and dashboards in Learning Analytics systems make such data accessible for various stakeholders in education. We have developed iSAT as one such tool for researchers and practitioners assisting them in visual analytics of educational dataset to trace transition patterns. Interactive Stratified Attribute Tracking (SAT) Diagram (see Fig 6 for example) is a unified graph where vertically aligned nodes represents distribution of stratified categories based on attribute values of collected data. The links track the transitions across the phases or attributes for any given sample. Between each phase it is a complete bipartite graph. For example in a PI activity the stratification criteria can be correctness of answer. Figure 6 shows the correct and incorrect proportion as strata in each voting phase as nodes. Further iSAT tracks the transitions between each stratum of consecutive phases as the links. Information like the portion of the population who was incorrect in Q1 but later answered correctly during re-voting can be visually analyzed.

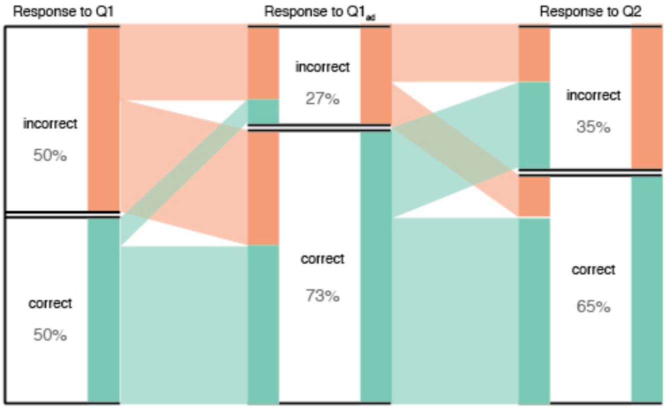


Figure 6. iSAT describing correctness of response across 3 voting phases in PI

In earlier works we have used a static version of iSAT to define a model of engagement during different phases of another active learning strategy known as Think-Pair-Share (Kothiyal, 2013). iSAT also helped to trace students performance across paper tests and problem posing activity, track online learners' performance in participation for completing and submission of assessment, and study consistency of survey responses across different questions asked to understand student's perception (Majumdar, 2014a). Further we developed a 2-phase dynamic version of iSAT to enable the user to use their own dataset and explore further transition properties of the cohort on-demand (Majumdar, 2014b).

iSAT can be incorporated in the activity flow of classical PI (as shown in Fig 2) or when extended with isomorphic Q2 (see Fig 7). In the next section we demonstrate its utility to explicate patterns given the data for PI responses.

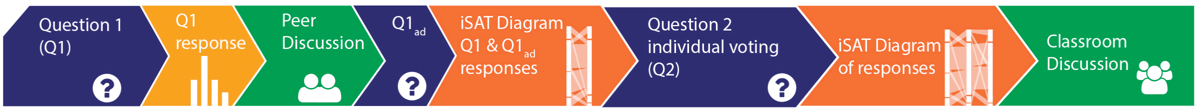


Figure 7. Cohort analysis by iSAT for modified PI with isomorphic question.

3.2 *iSAT for learning analytics of PI*

Using iSAT diagram we can explicate real time response trends during a PI activity, which would assist the instructor to take more informed decision regarding the subsequent activity design in an active learning class. Figure 2 illustrate the minimal deviation from the workflow of classical PI to include iSAT. With the data being collected through any Clicker system each collected response data is already linked to a participant by logging the answers corresponding to a device ID. Feeding that clicker data as input, our system computes and visualizes an iSAT diagram. It can help both instructors and researchers to look into a level deeper in the response data than Histogram or Flow charts to explicate transition patterns. Such transition patterns can be further categorized to assist instructors to reflect on cohorts in the students and investigate their learning characteristics. Figure 8 illustrates a static render of iSAT diagram for our regenerated data set.

iSAT has two modes. The initial Overview mode (see Fig 8) provides the static distributions of each nodes and transitions in between them. The user can interact with that through click/tap to explore further details of any cohort during the Exploration mode (see Fig 9).

Overview mode: the initial static visualization

Figure 8. iSAT for the generated PI response data (N =100)

The stack with vertically aligned blocks corresponds to a phase. For PI Clicker data each round of voting is considered as a phase. Each block corresponds to a stratum in the iSAT framework and here they represent option answered in a particular phase of voting. In Fig 8 the top block in second column conveys 73% of the students voted option 1 during re-voting phase, the right wall is proportional to that 73% of the full column. The left wall of that block gives distribution of those 73% cohort with respect to the previous phase. The links (band) on the left and right visualize the cohort that is transiting between any strata of two consecutive phases. Its width is proportional to the transitional ratio with respect to the whole population size.

Exploration mode: views while interacting with the diagram

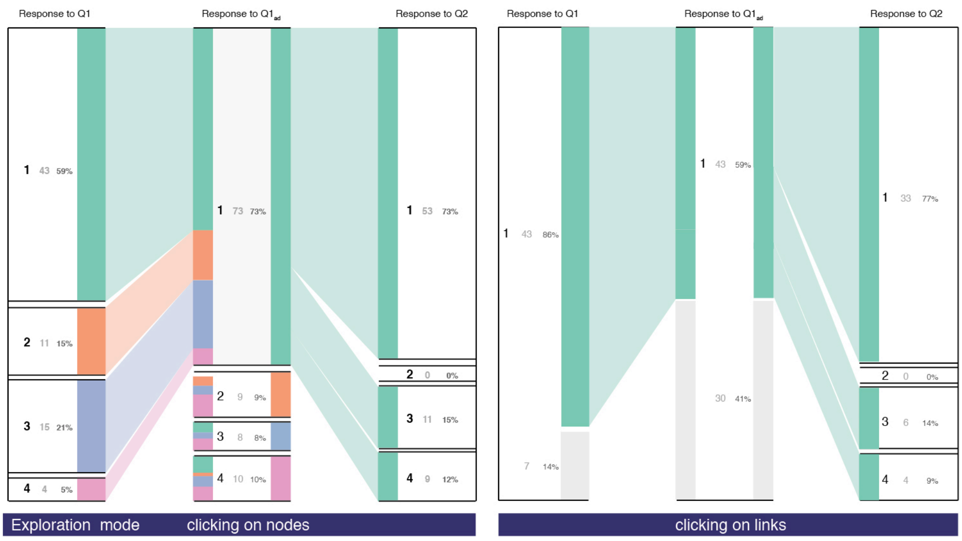


Figure 9. Interaction instances of iSAT for exploring details-on-demand

To explore details of proportions the user can click/tap on either any of the boxes corresponding to the stratum or any links corresponding to a specific transition. It helps them select the cohort whose details need to be explicated. When the cohort corresponds to a specific category in a phase then there is a transformation of the diagram and in each phase the distribution of the corresponding cohort is visualized. For example in Fig. 9a when the user clicks on the correct category of response in $Q1_{ad}$ (option 1) they get the details of that 73% cohort, in which strata and what proportion do they belong in Q1 and their response distribution in Q2. So instructors is informed 59% of the people who are correct after re-voting were initially correct also and 73% of them answer the Q2 correctly.

When the user clicks on a transition cohort, the diagram highlights migration pattern for that cohort of students across the phases. For example in Fig 9b it visualizes and tracks the cohort that was correct in Q1 and $Q1_{ad}$. 43% of the population belongs in this cohort. It compromise 86% of the correct response group during individual voting, and 43% of the correct response during re-voting. Further it conveys 77% of that cohort answers Q2 correctly and in the 23% of the incorrect responses 19%'s answer is option 3.

3.3 Patterns explicated by iSAT and how instructors can interpret them.

iSAT explicates the rich transition patterns in the three phase isomorphic PI activity response. The visual structure of iSAT helps an instructor understand the pattern and its interactive dynamic nature allows them to explore further details about those transitions. We explored all the 64 possible transition patterns across 3 voting phase each having 4 options. Out of them we defined 7 categories of specific transition patterns, which can be interpreted by the instructor who is conducting the PI activity. It also signifies cohorts of interest. Some of the patterns of interest were adopted from the consistency plot analysis done in context of physics education research to analyze pre-post student responses [Wittman et.al (2014)].

3.3.1 Aligned Pattern

Aligned cohort remains in the same strata across phases. A bigger population of *Aligned* correct would probably indicate most students had the concept right and hence consistently answers correctly across the voting phases. The instructor can take it as a cue to go forward and introduce the next topic. *Aligned* cohort to incorrect response indicates that cohort requires attention to learn the concept, as they fail to answer both the question correctly across three phases of voting. In our dataset 34% of the population voted the same choice across 3 phases with 33% consistently answering the right option and 1% was incorrect who never even switched response option from 3 (see Fig 10a). If the *Aligned* incorrect population proportion is considerably more then the instructor knows that cohort is always stuck in the alternate conception linked to option 3. Further Fig 10b shows the alignment between two consecutive phases. 86% students, who gave the correct answer (option 1) in Q1, reaffirmed their choice after the peer discussion. Considering only the first two phases, this cohort represents the *Control Group* (as defined by Porter et.al 2011). Across three phases they belong to the cohort that contributes to the denominator of the Weighted Learning Gain. Interestingly pairwise response alignment show 3% and 2% of students answer option 4 across the voting phases respectively, but none consistently get it wrong by answering 4 all the time. Such analysis is not possible by plotting histograms or flowcharts.

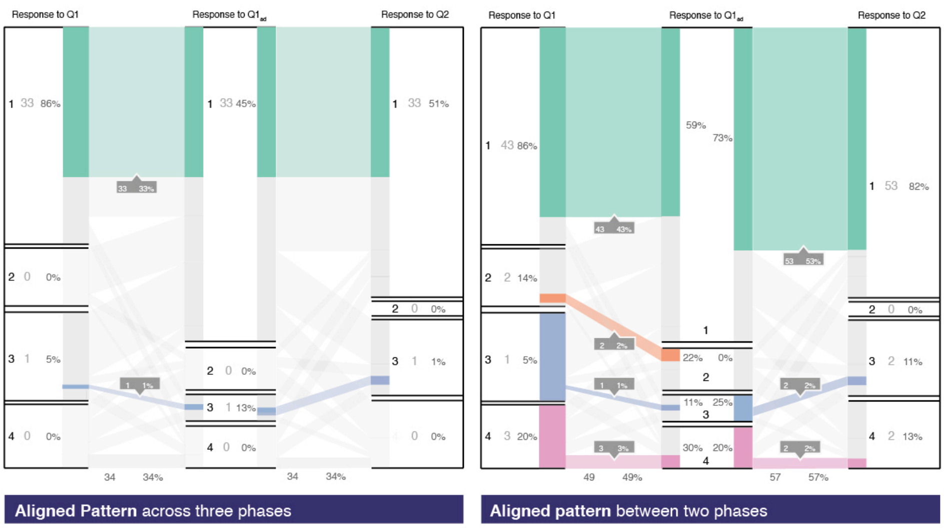


Figure 10. Aligned patterns a. across three phase b. between two phase c. Returns pattern

3.3.2 Returns Patterns

The portion of the population who give an initial response and change it in the second phase but later returned back to the original response category forms a *Return pattern*. The instructor can identify the proportion of these students who are inconsistently correct and give specific scaffolds for their learning. In our data 4% changed the answer from right to wrong and then again answered Q2 correctly and another 4% were initially wrong and rectified after PI but answered Q2 incorrectly (see Fig 11).

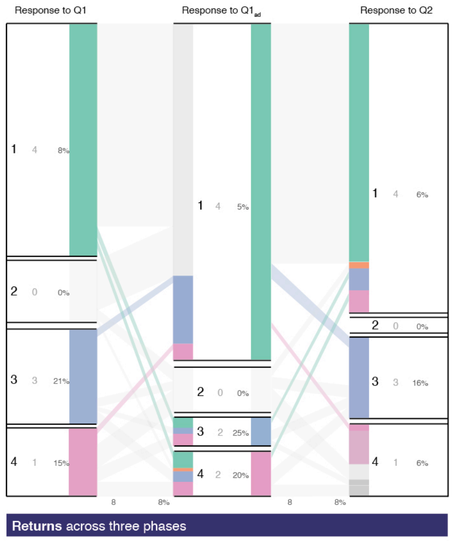


Figure 11. Returns pattern across three phases.

3.3.3 *Starburst*

A portion of the cohort that migrates out of a particular stratum in a pre-phase to other more desirable strata in the post-phase generates a *Starburst pattern*. In the context of PI between two phases of voting when some students are initially incorrect then becomes correct in the next phase they highlight the starburst pattern (see Fig 12 a). In our dataset, 30% of the students *Starburst* between Q1 and $Q1_{ad}$ and 12% from $Q1_{ad}$ to Q2. *Starburst* from the incorrect response is desirable from the first phases. The instructor also identifies the cohort of *Potential learner group* (refer Porter 2011 for definition) who benefited from the PI activity.

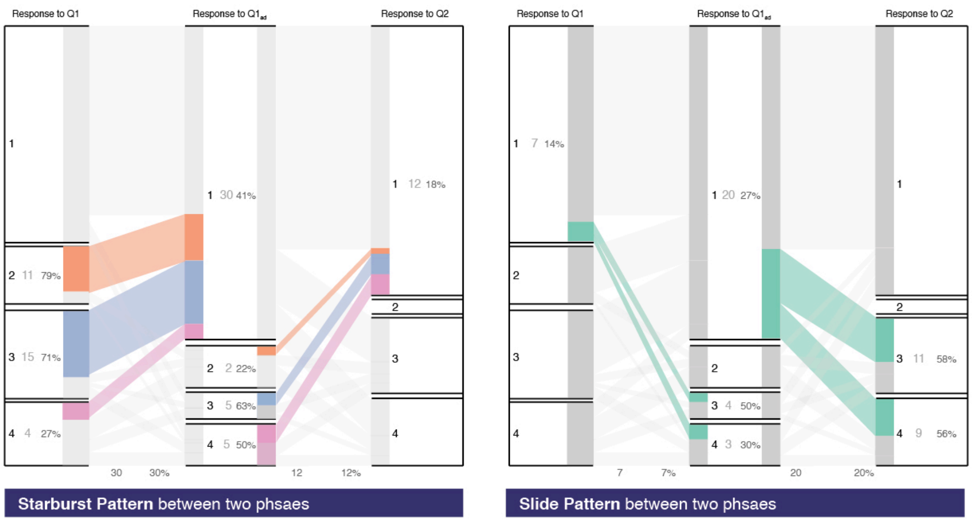


Figure 12. a. Starburst patterns b. Slide patterns

3.3.4 *Slide*

A portion of the cohort that transits from a desirable stratum in the pre-phase to a less favorable stratum in the post-phase generates a *Slide pattern*. In the PI case, the transition from a correct answer to an incorrect answer across two phases of voting generates a slide. Since *Slide* from the correct to incorrect is undesirable, instructor can create specific activities that address the misconception that may be causing the slide. Figure 12b highlights the cohort that slide from correct answer to an incorrect response across voting phases in our example. 7% of the student slide after individual voting and 20% slide during Q2.

3.3.5 Attractor

A portion of the cohort that migrates into a particular stratum in a post-phase from other strata in the pre-phase generates an *Attractor pattern*. Considering the answer option 3, the attractor pattern would highlight the cohort that has transition from other strata in the pre phase to the one of option 3 in post phase. For only one desired stratum, tracing the attraction pattern corresponding to option 1, we shall get the same plot as Starburst. Instructor can compare attractor patterns for the different wrong option and can decide which alternate conception can be addressed in the post PI discussion.

3.3.6 Switching

Between two strata a portion of one cohort can transit to the other across phases. A pair of such cohort represents a *Switching pattern*. Figure 13a highlight the switching patterns in our dataset. There are 3% who gave answer as option 3 changed their response to option 4 while an equal 3% switched it from 4 to 3. A total of 51% of the population migrate option choices in Q1 during two voting phase and 43% for the second transition. Minimum 11% of the population switch in pairs, for each first and second transition. *Switching* patterns between incorrect responses highlight there exist a cohort who change their responses across two phases but still remain incorrect. A higher proportion of them might indicate higher engagement, but not necessarily improved learning. The instructor can evaluate which cohort of switching is most prominent and decide on some activities for clarifying both the groups.

3.3.7 Void

When no transitions take place between any two strata, they form the *Void pattern*. For e.g. there is no cohort that migrates from a correct answer to choose an incorrect option 2 during re-voting (see Fig 13b). Similarly none of the students change from option 2 to 3. *Void* transitions between a correct to incorrect response are desirable. If there is *Void* in an incorrect category then it indicates that such alternate conceptions no longer exists after the intervention. In our regenerated dataset the response as option 2 decreases and during Q2 none of the students answered it. Linking it to alternate conception, the pattern highlights the possibility that PI activity helped in conceptual understanding of the student to eliminate the specific wrong approach in option 2 totally over the isomorphic question activities.

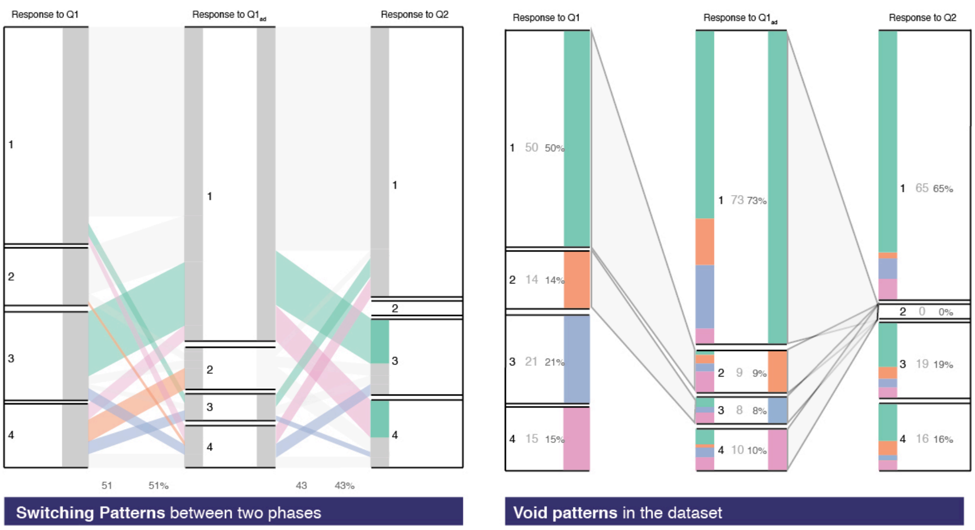


Figure 13. a. Switching patterns b. Void patterns

4. Discussion

Peer Instruction (PI) is an easy to implement active learning strategy. In PI activities, clicker data log across multiple phases of voting can have rich patterns implicit in it. It is difficult to interpret these patterns until they are visualized. Visualizations like Histogram and Flow Chart convey aggregate data, but miss the finer patterns. Our iSAT tool enables an instructor to explicate the patterns at an appropriate level of granularity and explore them interactively in real time.

In this paper we detailed the usage of iSAT to explicate the patterns that emerge during any PI activity. Going beyond traditional aggregate analysis through Histograms and Flow diagrams, we can analyze for cohorts in the population. This can help the instructor to assess the PI activity across voting phases, identify critical cohorts and subsequently take informed decision regarding post PI activity. The cohorts of interest emerge out of the iSAT pattern visualization. The instructor can check proportions of specific cohorts, such as those which are consistently correct or incorrect (*Aligned* pattern*),* cohorts which improve after the PI activity (*Starburst* pattern), cohorts which are initially correct but then cannot answer Q2 correctly (*Slide pattern)*, or cohorts which switch answers but still remain incorrect (*Switching* pattern). Such pattern categorization is useful for the instructor to make informed decision regarding next activities. For example, if the *Switching* pattern is observed, the instructor can highlight the differences between the corresponding concepts.

For a typical PI activity with isomorphic question at the end, we have identified seven patterns that can inform an instructor's post PI actions. These pattern detections are afforded by the designed views and interactions provided by iSAT. Interesting queries that the instructor might want to answer regarding the class dynamics can be categorized as patterns in iSAT. Longitudinally, iSAT could help the instructor to reflect across multiple PI activities by comparing patterns from each of them.

The iSAT tool can also assist researchers to identify new patterns that might provide other insights regarding cohort behavior. The utility of iSAT can be extended to online MOOCs also. It can be used for extensive learning analytics by researchers and the online instructor. They can identify specific cohorts and then give them personalized exercises for improving conceptual understanding. Critical cohorts who always remain incorrect across phases can be identified. Any attraction towards a specific misconception can also be observed and addressed explicitly.

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