Visual Analytics of
Cohorts in Educational Datasets

Submitted in partial fulfilment of the requirements

For the degree of

Doctor of Philosophy

by

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Dedication Sheet

Dedicated

to

Ma & Mima

(Dr. Sriya Majumdar & Smt. Deepa Ray)

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea / data / fact / source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources, which have thus not been properly cited, or from whom proper permission has not been taken when needed.

Rwitajit Majumdar

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Approval Sheet

This thesis entitled **"Visual Analytics of Cohorts in Educational Datasets"** by Rwitajit Majumdar is approved for the degree of Doctor of Philosophy.

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Chairman

Date: 30 - 04 - 2018

Place: Mumbai

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Abstract

Learning Analytics is one of the focus areas to understand teaching learning practices in the current technology enabled learning era. The insights gained thereby assists to design better learning experience for students. We consider three levels to analyze learning data. A Micro level view focuses on an individual learner. A Macro level view focuses on the overall group of learners, for instance a class of students. A Meso-level views analyze cohorts (sub-groups) in those learners. In this thesis we have conceptualized Interactive Stratified Attribute Tracking (iSAT), as a meso-level visual analysis model for educational data. It helps to track transitions across time or across attributes of collected data and thus build a narrative about the learners or learning context as it changes across time or across attributes. I adopted Design and Development Research methodology to conduct the research in three phases. Initially in the Need and Context analysis phase, I established the need of analyzing transitions at a meso-level by stakeholders. I also reviewed the current learning analytics techniques for analysing cohorts and the limitations of existing dashboards and visualizations to support such an analysis. Based on those findings, I set the goal of design, development and evaluation. Next, in the Design and Development phase, I followed the Design Science paradigm to create iSAT model for visual cohort analysis at the meso-level. There were three stages in the design and development phase; (i) Genesis stage of the iSAT model, (ii) Refinement of that model and (iii) Implementing the iSAT model as a web-based free access tool. I defined the constructs of that meso-level analysis and evolved the methods involved in generating, representing and interpreting the information. iSAT model was applied by 12 researchers in 9 different scenarios to analyze their educational datasets, resulting in 12 peer-reviewed published research studies (6 conferences, 1 journal and in 2 thesis). Further, to proliferate the iSAT model and tool among stakeholders, we conducted 4 iSAT workshops in 3 international conferences and 1 in-house symposium. In the Evaluation phase, we synthesized the usefulness of iSAT model from the 12 case studies, studied perception of first time users of iSAT and analysed applicability. iSAT helped both instructors and researchers to provide an overview of the transition patterns based on which they understand dynamics of the cohort and compare them. It can aid instructors in instructional decisions making and researchers to refine their analysis from the point of view of cohorts. The mean SUS score for iSAT tool was 71.57, indicating it as an acceptable system for analysis by the users.

Keywords: Learning Analytics, Cohort Analytics, Visual Analytics, iSAT.

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Abbreviations and Acronyms

AL	Active Learning
APIT	Automobile Project Implementation Template
CSER	Computer Science Education Research
DDR	Design and Development Research
DS	Design Science
HOTS	Higher Order Thinking Skills
IPT	Idea Planning Template
iSAT	Interactive Stratified Attribute Tracking
LAD	Learning Analytics Dashboard
LOTS	Lower Order Thinking Skills
PBL	Project Based Learning
PI	Peer Instruction
RQ	Research Question
SAT	Stratified Attribute Tracking
SPT	Study Planning Template
SUS	System Usability Scale
TAM	Technology Acceptable Model
TELE	Technology Enabled Learning Environment
TPS	Think-Pair-Share

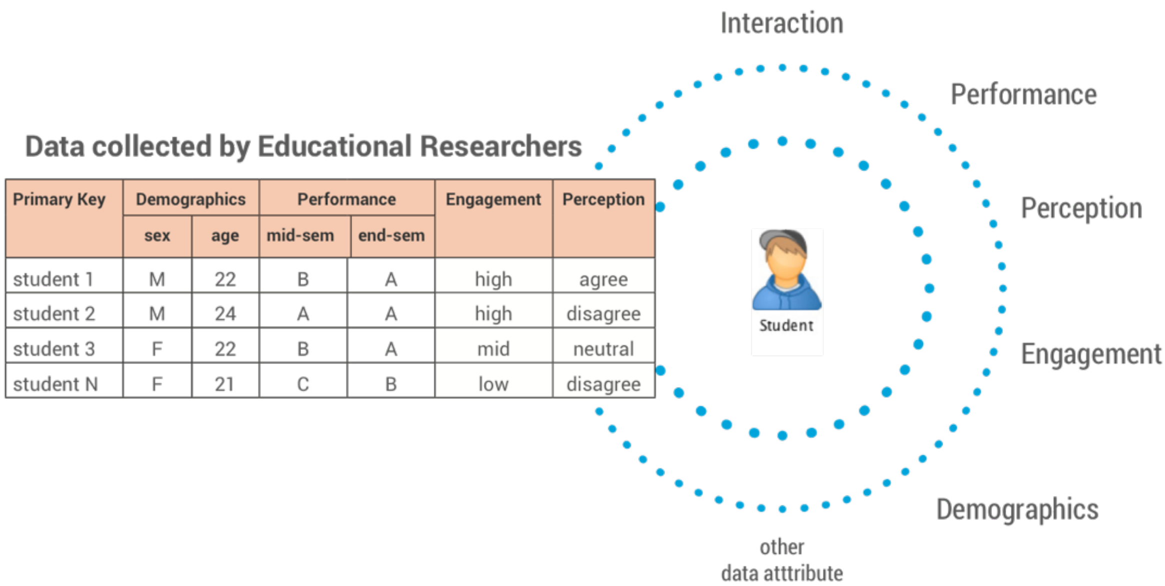
Chapter 1

Introduction

1.1 Background and Motivation

Technological innovations currently facilitate logging of granular data regarding any activity. Analysis of that data can assist understanding and decision making in the context of those activities. Research and practices in Business Intelligence, Medical Analytics and Data Science focus on such data-driven decision-making processes. Similarly, for Education, analytics helps to understand the dynamics of the teaching-learning context and thereby can assist in decision making to enrich the learner's experience, in terms of engagement, learning, personalization and so on.

Both instructors and educational researchers are interested to understand the changes observed in students due to their experience in the teaching-learning environment. Figure 1.1 illustrates typical attributes of the student data, that are collected in such a teaching-learning scenario.


Data collected by Educational Researchers

Primary Key	Demographics		Performance		Engagement	Perception
	sex	age	mid-sem	end-sem		
student 1	M	22	B	A	high	agree
student 2	M	24	A	A	high	disagree
student 3	F	22	B	A	mid	neutral
student N	F	21	C	B	low	disagree

Figure 1-1 Illustrative student data attributes

Justus J. Randolph (2008) describes four major approaches to analyze educational data (see Table 1.1 for some examples of each approach):

- Quantitative analysis of Quantitative data - Quantitative analysis of quantitative data is assisted by various statistical techniques.

- Quantitative analysis of Qualitative data - Method such as quantitative content analysis (Neuendorf, 2016). Such techniques are used in order to count distribution of different themes in coded qualitative data such as interviews, written artefacts and videos are example of doing quantitative analysis of qualitative data.

- Qualitative analysis of Qualitative data - Methods such as ethnography, phenomenological methods, grounded theory and case study, wherein rich descriptions and theories are developed regarding an activity or phenomenon of interest are examples of qualitative analysis of qualitative data

- Qualitative analysis of Quantitative data - Creating a graph of quantitative data is an example of qualitatively analyzing quantitative data

Table 1-1 Data and Analysis matrix

	Qualitative Data	**Quantitative Data**
Quantitative Analysis	quantitative content analysis	statistical techniques
Qualitative Analysis	ethnography, phenomenological methods, grounded theory	***visual analysis of quantitative data - creating a graph of quantitative data is an example of qualitatively analyzing quantitative data***

The issue with quantitative data, numbers as it were, is that it is often hard to understand the story that they are telling about the actor, the activity or their context. A qualitative analysis of quantitative data thus seeks to discover the story behind the numbers. Visualizations such as graphs are known to aid in the development of such a narrative and guide the data-exploration process (Shoresh and Wong,2012).

In this thesis, with the goal of aiding narrative building regarding educational contexts, we develop an approach for qualitative analysis of quantitative data, that assists exploration of relations and produce insights regarding subgroups with visualising transitions in educational datasets.

1.2 Setting perspectives of data analysis

In the educational context, instructors and researchers often analyze data from the perspective of an individual student (micro view) or at class level (macro view). For instance, at a micro level the instructor can look at an individual's performance score in assessments and monitor his/her achievement in any course. At a macro level, the instructor can aggregate information of individual students to get the distribution and mean of the whole class. Both the macro and the micro views help to understand particular teaching-learning dynamics; instructors monitor the progress of each student at the micro level and can gauge the effectiveness of their teaching strategies in the classroom at a macro level. Similarly, researchers can also take a macro level perspective on student performance data to evaluate and compare effectiveness of different classroom interventions. A micro level analysis can assist them in developing personalized learning modules for individual students.

Currently information and communication technology (ICT) in education enables collecting multiple students' attributes such as their demographics, academic performance, engagement, perception, interaction patterns and others. At a macro level, statistical methods like ANOVA and regression modelling helps to analyze multi attribute data. Researchers can get insights regarding relationship between the dependent attributes or which is affected most due to variation of the independent variable. But applying such insights in practice by instructors often requires the advanced statistical knowledge and hence is difficult. At a micro level, there are variations in individuals' attribute values and interpreting these trends in the context of their learning also remains difficult. For instructors and researchers from various domains, building such models and extracting trends can be quite challenging.

In this macro-micro spectrum, analyzing sub-groups of learners in the same class, can be considered as a meso-level perspective. For instance, learners in a class can be grouped based on their attribute values, such as high-medium-low performers based on their performance score in each test. We consider this sub-group of learners in a class as a cohort in the meso-level view (see Fig.1.2 for the different levels of view). This meso-level can assist instructors to further take specific instructional decisions based on the nature and distribution of those cohorts in their class.

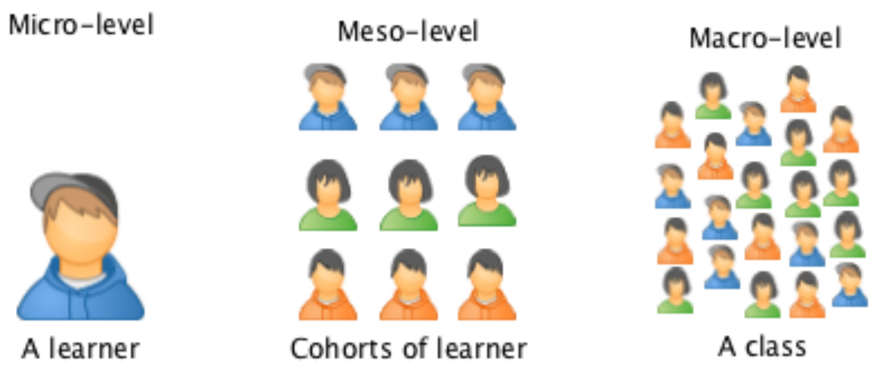


Figure 1-2 The levels of views

1.2.1 Illustrative example

Consider a typical Educational Technology (ET) research setting where the researcher studies a class of students learning in a technology enabled learning environment (TELE). Each learner takes a test before and after they interact with the TELE and their performance data and interaction logs are collected (see fig 1.3).

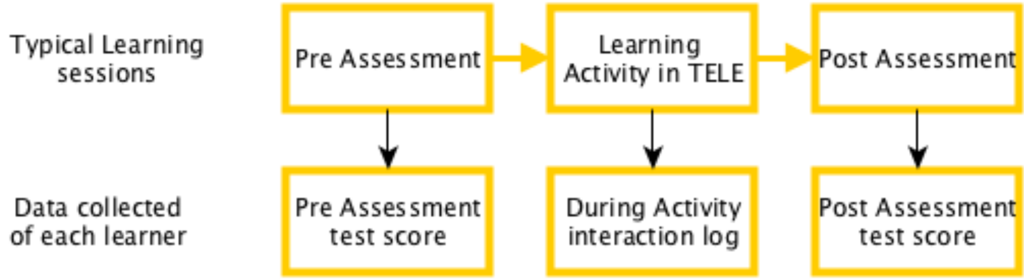


Figure 1-3 Illustrative ET research context and data collected in them

At the micro level, the researcher's focus is on one learner (see fig 1.4). For instance, a research work that aims to support personalization of learning through technology, often build data-driven models of a learner. The researchers can apply data mining techniques on the interaction data to retrieve information regarding an individual learner. This can help to monitor the activity of that individual in the TELE and decide about individual feedback.

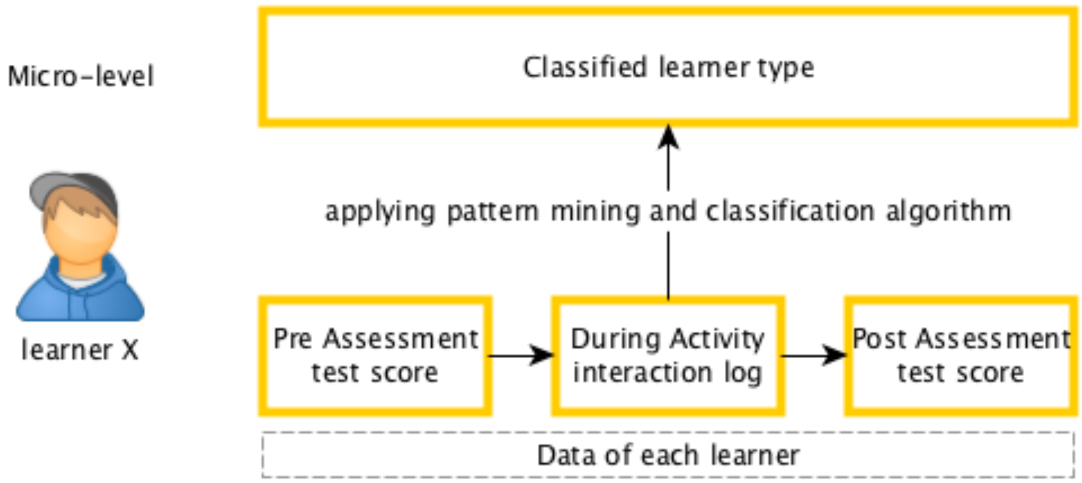


Figure 1-4 Micro level analysis of individual learner

Line graphs is one way to visualize the amount of time spent by the student in each module of the TELE during any activity (see 1.5). But the researcher cannot analyze what proportion of the class exhibits similar pattern of interaction.

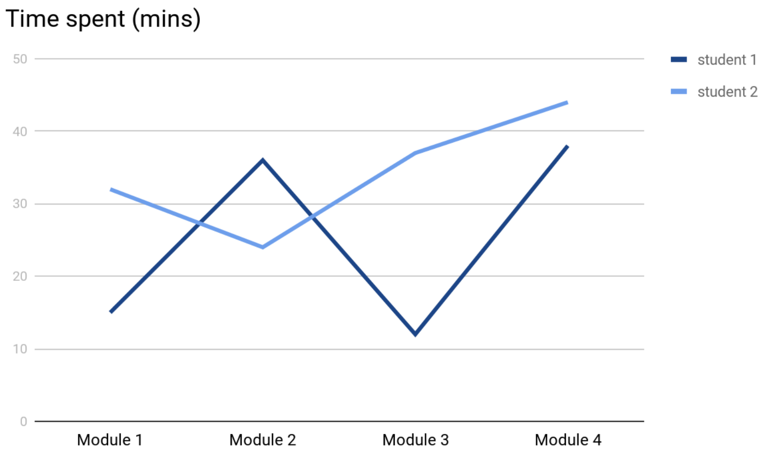


Figure 1-5 Line chart for representing individual's time spent in TELE at Micro level view

At the macro level, the researcher's focus is on the whole class (see fig 1.6). From that perspective one can evaluate the overall effectiveness of the TELE for that class by testing significance of the difference in the average score between the pre and post-tests. In similar scenarios, applying the statistical techniques at a macro level help researcher to draw inferences on performance gain of the students.

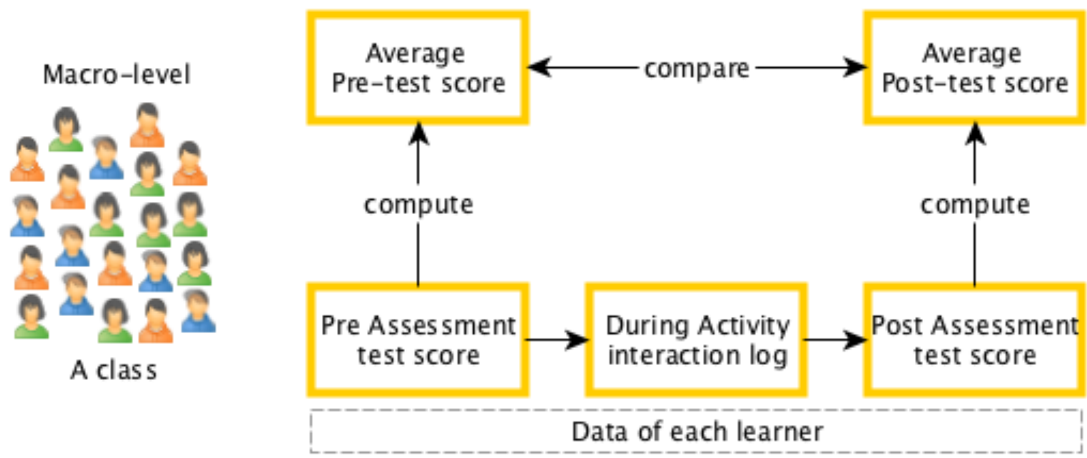


Figure 1-6 Macro level analysis of the class

Bar charts is one way to visualize the information for reporting (see fig 1.7). Each bar represents the level of average marks of the class in the pre and post-test respectively. Often during reporting researchers put an asterisk on the top of the pair of bars to indicate that the difference in the two mean values are statistically significant. Still the notion of individuals' score becomes irrelevant in the bar chart representation.

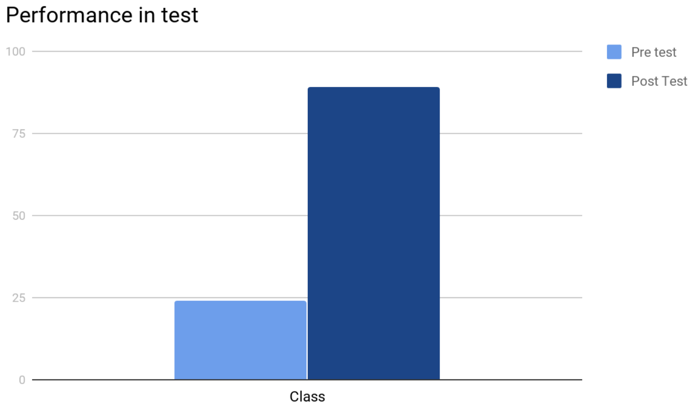


Figure 1-7 Illustrative bar chart for representing average scores at Macro-level view

In a context where students' performance and interaction log data are collected, researchers may want to focus on the proportion of the low performers who were high in active engagement, but still remain low performers in the post test. The proportion of such a group of students is not evident from either the line chart in figure 1.5 or the bar chart in figure 1.7. However, knowledge of this proportion helps build a narrative regarding the relationship between engagement in the classroom and test performance. Apart from individual feedback, researchers or instructors may want to group together students of similar profile in a class, such that the instructor can address them together or the researchers can investigate them in detail. Such scenarios of analyzing cohorts within a class can be considered forming the meso-level perspective.

While there are quantitative methods like clustering, literature doesn't discuss any educational data analysis model at the meso-level which takes the approach of qualitative analysis of quantitative data by visualizing it. In this thesis, I focus on how to analyze teaching-learning data from the meso-level perspective and investigate the utility of information that it provides. The research goal is to conceptualize a model and tool for visual analysis of cohorts in educational datasets.

1.3 iSAT: A Meso-level analysis model

We conceptualized Interactive Stratified Attribute Tracking (iSAT), as a meso-level analysis model for educational data. It helps to track transitions across time or across attributes of collected data and build a narrative about the learner or learning context as it changes across time or across attributes Figure 1.8 describes the meso-level view as an analysis plane focusing on cohorts (sub groups) of learners, in between the macro (class level) and the micro level (individual) view.

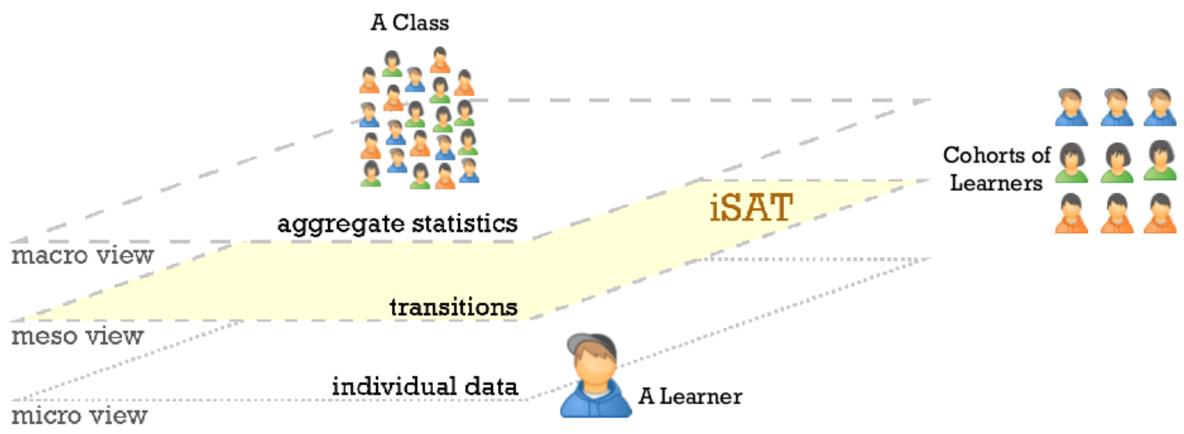


Figure 1-8 iSAT as a Meso-level view of the dataset

We developed iSAT by adopting Design Science paradigm (Henver et.al. 2004). The process involved creation of an information artifact by defining its constructs, methods and model. The constructs define the elements of the meso-level information regarding a cohort (see Table 1). The methods describe how to transform the data to generate the meso-level view and interpret it. A prescriptive model emerges based on the constructs and methods that assists data analysis from a meso-level perspective

Consider the illustrative example described in previous section. In the iSAT model, performance and engagement attributes are the two phases. The researcher can create groups of different levels of the attributes based on some criteria and represent strata such as High-Medium-Low (HML). Transitions between phases would indicate the number of records which belong to specific strata in one phase and another stratum in another phase. See Table 1.2.

Table 1-2 iSAT constructs for Meso-level analysis

Constructs	What does it define	Example
Phase	Any attribute which is collected can be represented as a phase	Performance can be represented as a phase
Strata	The specific groups defined by criteria set on attribute values defines strata	High performer can be represented as a stratum
Transitions	The migration of cohort in one stratum to another is represented as transition	Across different assessments, transition can represent the proportion of the low performers who become high performers

The iSAT diagram represents these constructs and their values visually. Researchers can apply the iSAT model and use the visualization to analyze patterns of transitions across different attributes or across time in their context (see Fig 1.9).

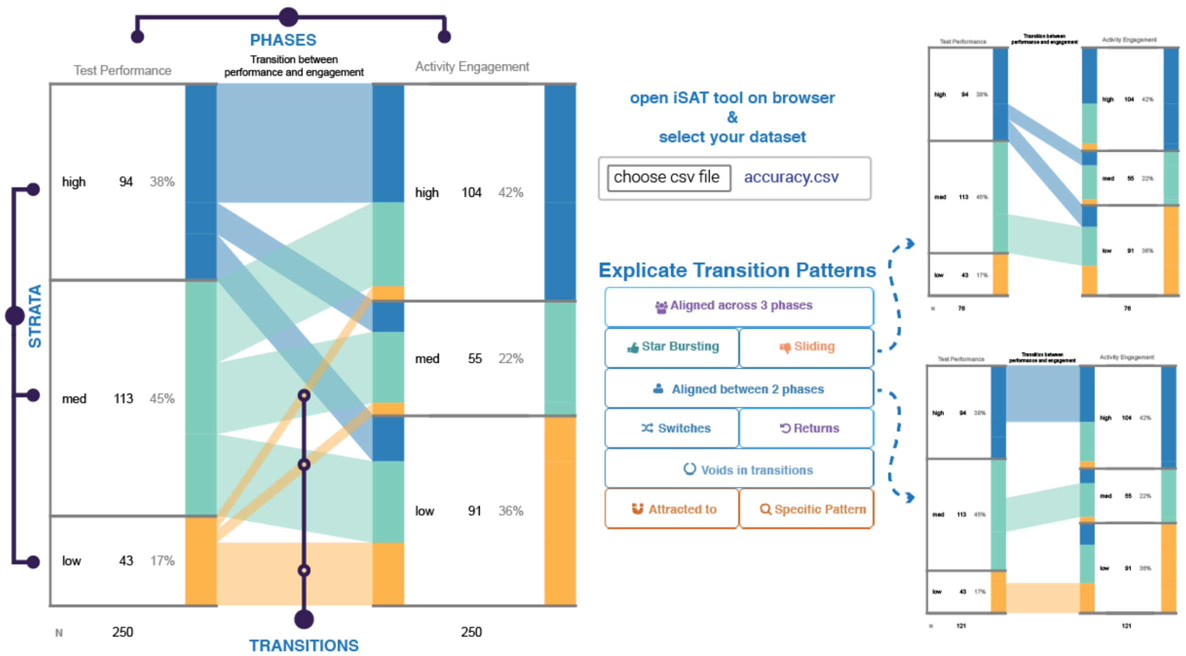


Figure 1-9 The Interactive Stratified Attribute Diagram as a visual representation of the Meso-level view

To assist users in analyzing data based on this iSAT model, we developed a web-based interactive visualization and analytics tool (accessible at www.et.iitb.ac.in/iSAT). To evaluate the usefulness of iSAT, I studied 12 cases in 9 different educational scenarios that applied the iSAT model to analyze their data. Both instructors and ET researchers were among the users of iSAT who analyzed data from face to face classrooms, online classrooms and other controlled educational research settings. The primary utility of iSAT was to assist building a descriptive model of the data at a meso-level in terms of transitions. For example, a researcher used iSAT to create a descriptive model of student engagement. Think-Pair-Share (TPS), an active learning strategy, was implemented in a large undergraduate class and researchers could use iSAT and capture the transitions of observed engagement levels across the three phases of TPS (Kothiyal et.al., 2013). Further studies in the same scenario compared the transition patterns of pre and post-test performances of two different groups of students, one of whom participated in the TPS activity and the other was exposed to interactive lectures (Kothiyal et.al., 2014). Similarly, an instructor used the transition patterns to select a number of participants from his online course for a further face to face in-service professional development program (Warriem, 2013).

The workflow of meso-level analysis through interactive stratified attribute tracking of datasets is summarized in Fig 1.10.

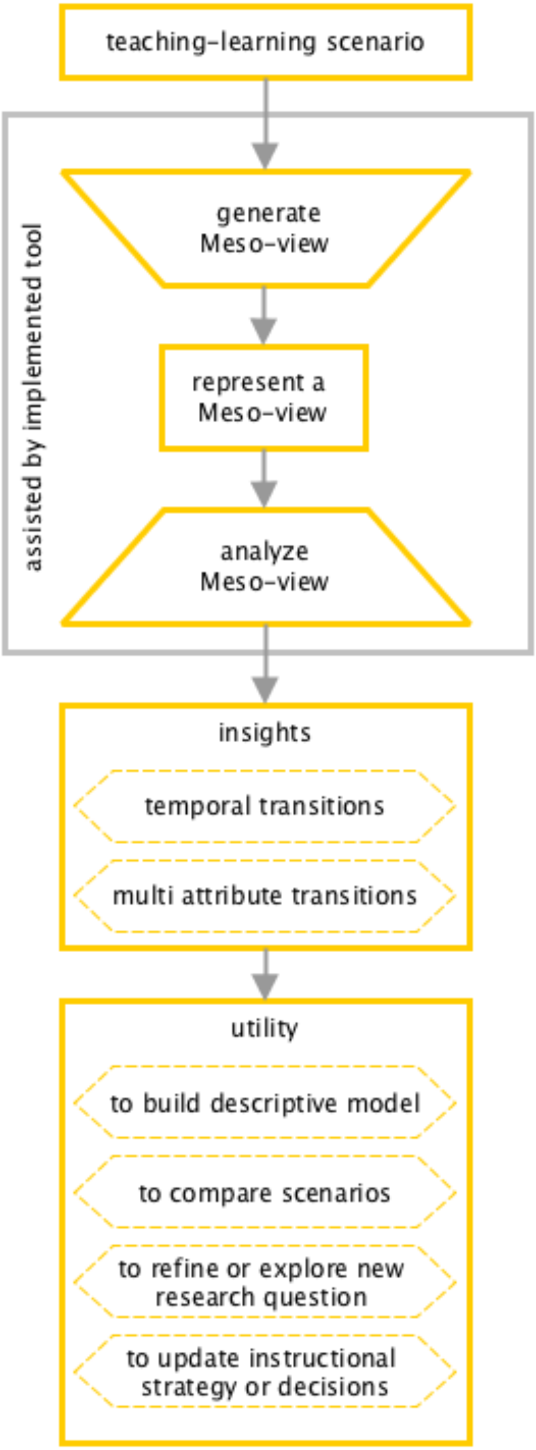


Figure 1-10 Workflow of the Interactive Stratified Attribute Diagram as a visual representation of the meso-level

1.4 Research Methodology

Design and Development Research methodology (Richey & Klein, 2008) is the overarching research methodology. There are three research phases as follows:

- Need and Context Analysis phase - In the Need and Context analysis phase I identified the need for this research and position our context of research. The output of this phase also help to synthesize the objectives of designing an information artifact and develop a tool.
- Design and Development phase – In this phase I conceptualized, formatively evaluated and refined our proposed solution. There were three stages in this phase; the Genesis stage of the meso-level analysis model, the Refinement stage and the Implementation stage to develop a web tool based on the designed iSAT model.
- Evaluation phase - In the Evaluation phase I studied how users interacted with the iSAT model in their own context. Our primary users were researchers and instructors. We conducted hands-on workshops to introduce them to the iSAT model and tool. The workshop participants studied the usefulness and usability of iSAT.

Across the three phases, various research methods were used to collect, analyze and synthesize data systematically. Reviewing literature and thematic analysis of interviews of stakeholders helped to understand the need and context of meso-level analysis. For evaluating the solution, I analyzed 12 reported use-cases of iSAT that highlighted its usefulness. Based on this analysis I built a model of how iSAT was utilized. I did quantitative analysis of survey responses and qualitative analysis of interviews to understand the perception of usefulness and usability of iSAT by first time users (instructors and researchers). I argue about the applicability of iSAT for different research scenarios on the basis of a meta-analysis of existing research studies.

1.5 Contributions of this thesis

The contributions of this thesis are listed below:

- Establishing a need for visualization-based analysis model of cohorts.
- Designing Interactive Stratified Attribute Tracking (iSAT) as one such model of visual analytics from a meso-level perspective. Further, developing an interactive visual representation, iSAT diagram and a web-based tool to assist users to generate the meso-level information and visually analyze trends.
- Establishing usefulness of iSAT by examining 12 use cases by various stakeholders (educational researchers and instructors).
- Demonstrating usability of iSAT model and tool after conducted four hands-on iSAT workshops for stakeholders and analyzing evaluation survey responses.
- Illustrating an instance of implementing DDR methodology to conduct learning analytics development research.

1.6 Organization of this thesis

In Chapter 2, I discuss our methodology choices and details of the selected Design and Development Research (DDR) methodology. In Chapter 3, I discuss the related literature to understand the problem space and our solution approach. Based on DDR, the findings of the need and context analysis phase is in Chapter 4. The next three chapters describe three stages of the design and development phase of DDR: The Genesis stage of the meso-level analysis model in Chapter 5, the Refinement stage in Chapter 6 and the Implementation stage of web tool development in Chapter 7. In Chapter 8, I provide the details of our developed iSAT model and tool. In Chapter 9 I report the published use cases of iSAT and evaluate the usefulness of the model. In Chapter 10 I describe the proliferation efforts of iSAT along with the results of the first-time users' perception studies. In chapter 11, I summarize the work done, its limitations and future directions of research. Figure 1.11 shows the organization of this thesis.

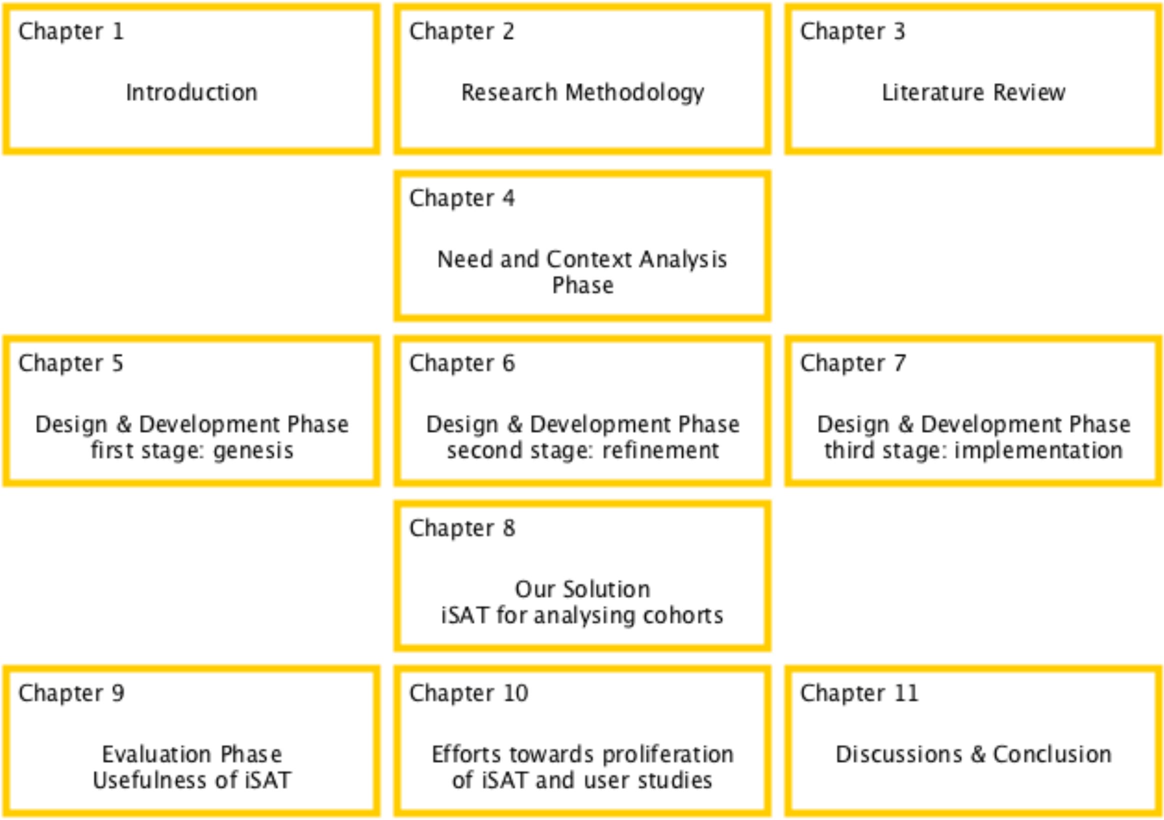


Figure 1-11 Organization of thesis

Chapter 2

Research Methodology

This chapter, elaborates on the methodology to pursue the overall research goal to conceptualize a model and tool for visual analysis of cohorts in educational datasets.

2.1 Approach of research inquiry

I took a constructivist worldview to conceptualize our model for these meso-level analytics (Cresswell, J. W, 2003). This would involve us to explore what is the meso-level view that the researchers and instructors use in their current context and how they make sense of it. The findings would then inform our design of an analysis model with visual representation of data at the meso-level. Further studying the usage of the model and tool in different educational data analysis contexts would highlight its utility.

I set an initial approach consisting of the following systematic steps:

1. Understanding the context / problem of a specific case.
2. Identifying the goals of the solutions.
3. Developing the solution by applying relevant inputs from the existing knowledge base.
4. Iteratively update the solution based on formative evaluation and feedback.
5. Evaluating the final working solution and reflecting on what contributions it made to the specific case and theory in general.

2.2 Candidate Research Methodologies.

Our approach of research inquiry we required an overarching methodology which supported iterative research design and applied both qualitative and quantitative methods to evaluate the research outcomes. Two possible educational research methodologies could assist to structure our overall work. They are:

1. Multiphase Mixed Method
2. Educational Design and Development Research

2.2.1 Multiphase Mixed Method

Mixed method research (Creswell, 2013) describes various design where both quantitative and qualitative methods are used to conduct research. Creswell describes an advance mixed method design, multi-phase mixed methods where each phase has one study that informs the next study in the next phase. In each study the researchers can use either qualitative, quantitative or mixed method research.

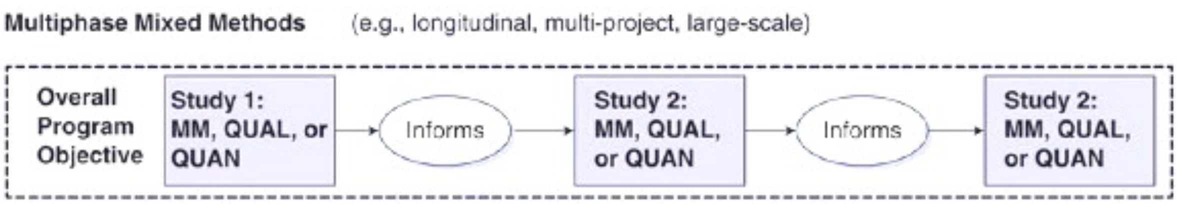


Figure 2-1 Structure of Multiphase Mixed Methods research (Creswell J.W, 2013)

This method is quite generic and largely fit to pursue the goal of conceptualizing and understanding the utility of a meso-level analytics. The overall design of the research to investigate specific aspects of the analytics concept would be required to be formed as studies to apply this methodology. Each study would then collect data that would be used to inductively build and validate the concept of meso-level analysis.

However, the methodology doesn't indicate the nature of the studies to be conducted and what kind of aspects of the concept needs to be defined by following a particular research process. Hence, we further looked for a specific methodology.

2.2.2 Educational Design and Development Research (DDR)

Educational Design and Development Research (DDR) is primarily implemented in Instructional Design research inquiries. It is "The systematic study of design, development and evaluation processes with the aim of establishing an empirical basis for the creation of instructional and non-instructional products and tools and new or enhanced models that govern their development" (from Richey R.C. & Klein J.D. 2014 where they quoted Richey R.C & Klein J.D., 2008, p. 748).

DDR reaches these goals through two main categories of research projects: 1. research on products and tools and 2. research on design and development models. These categorizations were previously referred to as Type 1 and Type 2 developmental studies (Richey, Klein, & Nelson, 2004). Rickey and Klein synthesized that others have referred to instructional product development studies as design-based research (Wang & Hannafin, 2005), systems-based evaluation (Driscoll, 1984), and formative research (Reigeluth & Frick, 1999; van den Akker, 1999).

DDR has the following characteristics (Van den Akker et.al, 2006):

a. Interventionist: Aspires to create an intervention for a real-life problem

b. Iterative: Involves cycles of analysis, design and development, evaluation and revision.
c. Practitioner involvement: The target user population is involved in all stages of the research
d. Process oriented: Focus is on improving and understanding the intervention. A blend of both qualitative and quantitative research studies is needed.
e. Utility oriented: Solution designed is contextualized. The research results are "connected with both the design process through which results are generated and the setting where the research is conducted" (Wang & Hannafin, 2005, p. 11)
f. Theory-oriented: The solution design is based (at least partially) on existing theories and conceptual frameworks while 'systematic evaluation of prototypes of the intervention contributes to theory building'. The theory-building can lead to one of the following three types of theories – Domain theories, Design framework, Design methodologies.

Ellis, T. J., & Levy, Y. (2010) describes 6 phases of the DDR approach (see Figure 2.2).

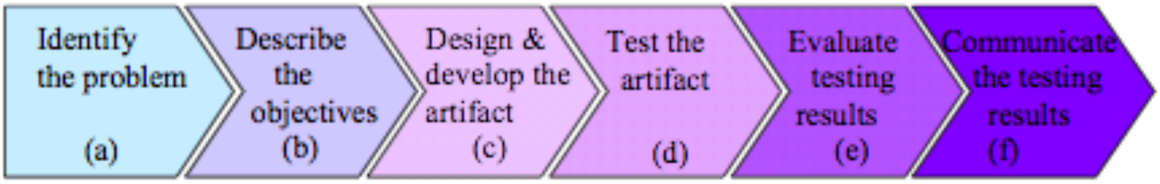


Figure 2-2 Six phases of DDR (Ellis, T. J., & Levy, Y. 2010)

Further the iterative nature of the approach is mentioned by Van den Akker, J. et.al. (2006), (see Figure 2.3).

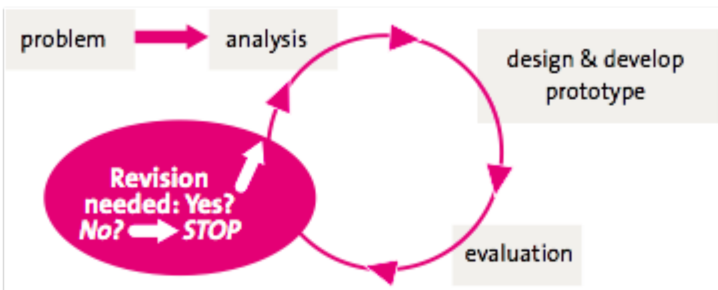


Figure 2-3 Iterative nature of DDR cycles (Van den Akker, J. et.al., 2006)

I analyse DDR's applicability of being the methodology of our research in terms of its suitability criteria as presented by Van den Akker, J. et.al. (2006). DDR also provided more detail in structuring the research process in terms of specific phases and indicating the outcome of a technology model and tool development project.

Table 2-1 Suitability of our research goal to adopt DDR methodology
(based on criteria mentioned in Van den Akker, J. et.al. 2006)

Criteria for suitability of DDR methodology	Our context
The chosen research problem	Developing and analysing a meso-level view of the dataset
Is the problem common to stakeholders (design and developers, in original text)	Yes researchers and instructors routinely collect data in their teaching learning scenario and need to analyse them to take decisions or have better understanding of their practices.
Is the problem critical to profession	Yes simplicity of analysis and ease of interpretation with respect to the context is critical.
Does the problem reflect realistic constraints and conditions typically faced by stakeholders (designers, in original text)	Making sense of data gathered in educational context remains a typical and realistic agenda for the stakeholders . For example for a novice researchers mining algorithm becomes difficult to implement and the results difficult to interpret
Does the problem pertain to cutting edge technologies and processes	Yes the research aims to implement Visual Analytics techniques in the domain of Learning Analytics.

2.3 The methodology used for this research

I adopted Design and Development Research methodology and had 3 distinct phases as shown in Figure 2.4. The first Need and Context analysis phase combines the first two phases of DDR as stated in Figure 2.2 (a. Identify the problem and b. Describe the objectives). Our second Design and Development phase maps to the phases c. Design and develop artifact and d. Test the artefact phase. Our third Evaluation phase maps to e. Evaluate testing results and f. Communicate the testing results. The iterative nature of the DDR cycles as given in Figure 2.3 is conducted during our Phase 2.

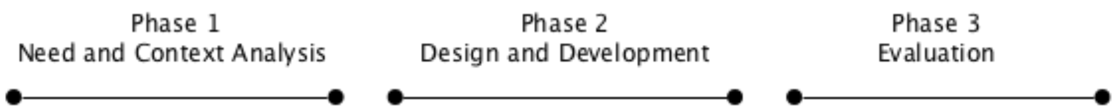


Figure 2-4 Phases of our research adopted from DDR

2.3.1 Phase 1: Need and Context Analysis Phase

In the need and context analysis phase I position the research inquiry in the context of the current state of art. By analyzing the literature and conducting preliminary studies, in this phase I synthesized the initial goals of our design and development. I studied the context of analyzing learning data focusing on subgroups of learners (or any other records) and how learning analytics community conduct them and utilize learning dashboards for that purpose. Further I gathered empirical data of the need of focusing on cohorts from teachers and support staffs. This helped to synthesize the initial goal. Our approach in this phase is presented in Figure 2.5 and details are in Chapter 4.

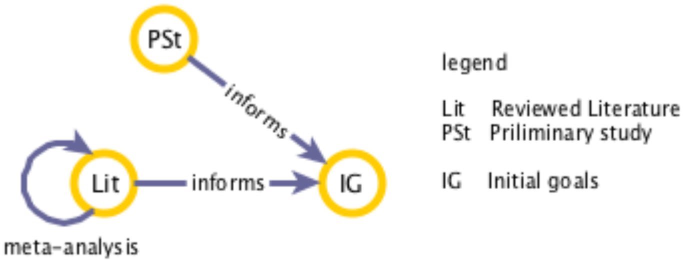


Figure 2-5 Need and context analysis phase

2.3.2 Phase 2: Design and Development Phase

The design and development phase have iterative stages. The first iteration is the genesis stage. Based on the initial goal an initial solution is designed. This solution is evaluated and then based on the feedback the goal is revised to refine the solution. Then one can have iterative stages of refinements or implementing the solution. In each stage, conceptual framework or an implemented system is designed, evaluated against the set goals. Once the goals are met, the solution / system can be accepted as a working solution and evaluated further during the evaluation phase. Figure 2.6. gives the structure of the design and development phase. In this work there are three stages in the design and development phase. Chapters 6 discusses the genesis stage, chapter 7 the refinement stage and chapter 8 the implementation of the tool. The iSAT model and the web-based tool is the working solution to analyze meso-level view of educational dataset.

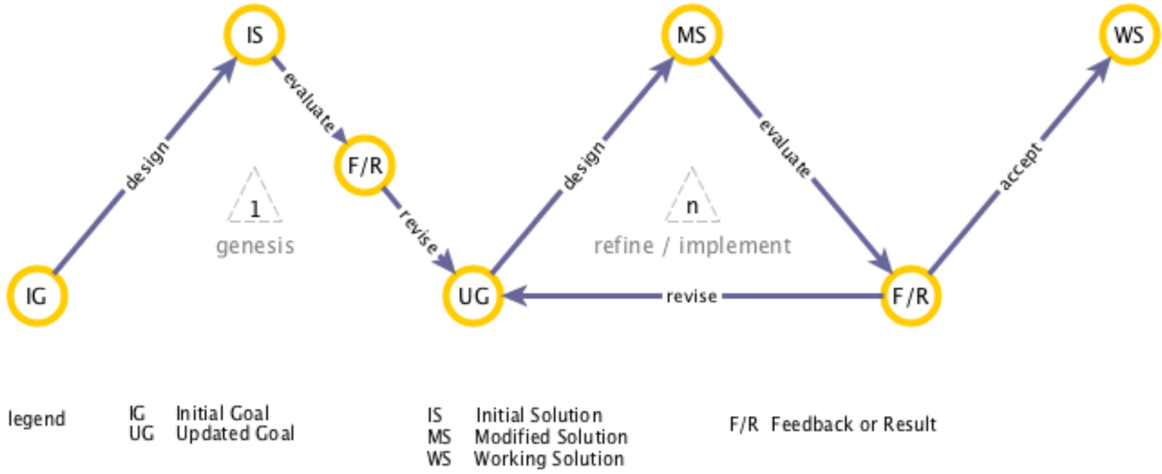


Figure 2-6 Design and Development Phase

Paradigm to build solution

The Design Science (DS) paradigm (Henver et.al., 2004) was used to develop an information artifact to analyze educational data from a meso-view perspective of cohorts. Design Science has its foundation in Information System research. In DS, knowledge and understanding of a problem domain and its solution are synthesized from building a designed artifact. The research framework followed in Design Science is presented in Fig.2.7.

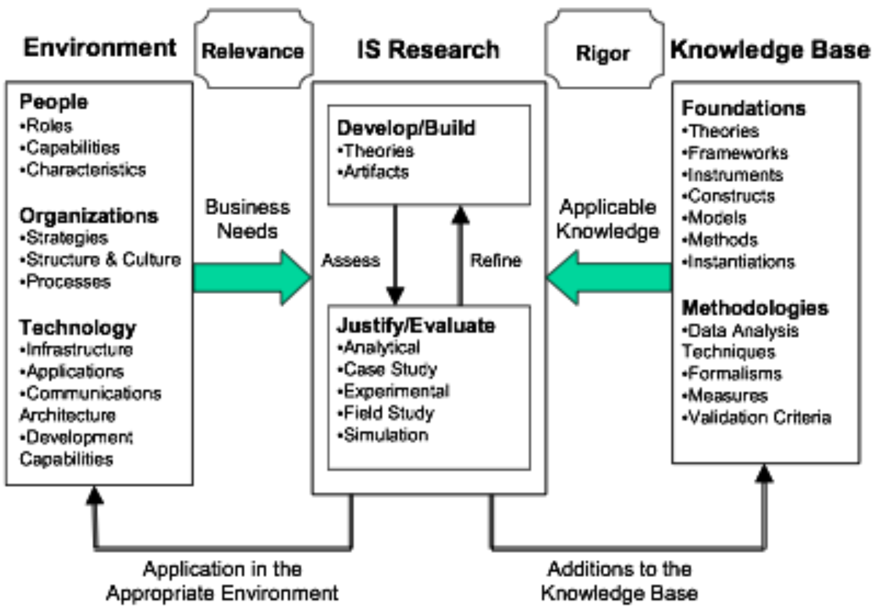


Figure 2-7 The research framework in Design Science (Henver et.al. 2004)

We adapt the different kinds of designed artifacts according to Design Science (see Table 2.2). While conceptualizing the Constructs, we attempt to give structure to information of cohorts at meso-level. We want to represent these information constructs by visual elements to assist analysis. The Methods would define how to generate the information from raw data and then interpret it. A Model of meso-level analysis would emerge as an output of the design and development. Studying Instantiation of this model in different contexts of analyzing educational data, would inductively inform the nature and utility of the meso-level analysis that it supports.

Table 2-2 Types of artifacts and what they provide

Artifact type	What does it define
Constructs	vocabulary and symbols
Methods	algorithm and practices
Models	abstraction and representations
Instantiations	implemented and prototype system

2.3.3 Phase 3: Evaluation Phase

During the evaluation phase different studies are conducted with the working solution (see Figure 2.8.). In Chapter 9 I discuss the case studies of usefulness of the developed working solution and its applicability analysis. In Chapter 10 I describe the stakeholder workshops conducted and the perception study of the first time users.

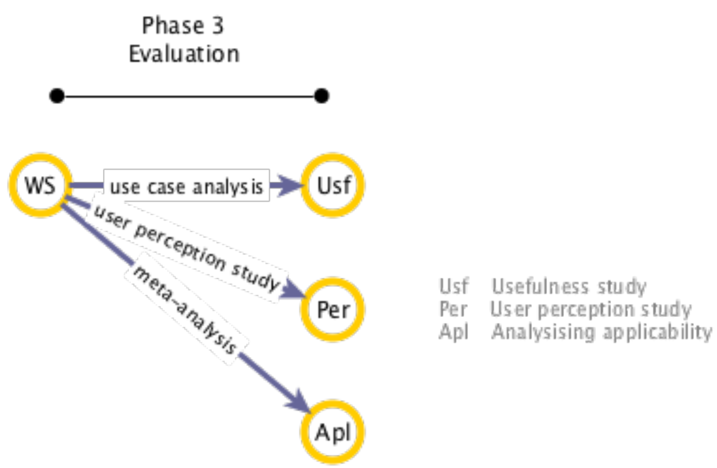


Figure 2-8 Evaluation Phase

2.4 Research Questions and Research Design

2.4.1 Categories of Research questions

In the course of the research three types of questions were answered.

Need and Positioning Question (NPQ) – These set of inquiry questions look into the context and clarify the problem domain and its scope. Their answers illustrate the current state of art and help to position our solution. They are primarily asked during the Need and Context analysis phase.

Design Question (DQ) – They relate to finding specific operationalization of theories or practices to design or develop artifacts or methods. They are asked during the Design and Development phase.

Evaluation Questions (EQ) – The answers to these set of questions help to evaluate the output and reflect of it. Some of them are asked in design and development phase during formative evaluation. Others are investigated during the Evaluation phase.

2.4.2 Research questions and design for this research

The research design links the research questions in each of the phases of the methodology to the methods to study them. The need and context analysis of this research work was done by conducting meta-analysis of literature and collecting primary data from the stakeholders.

In the design and development phase the meso-level view of the information was conceptualized in terms of its constructs, methods and representations. It was created and refined over two cycles and then a tool was developed based on that concept to assist the users. Across the design and development phase the formative evaluation of the generated information artifacts were tested in the context of use.

In the evaluation phase, I evaluated the usefulness of iSAT, the perceived usability and usefulness of first time users. Further I examined how iSAT can be applied to help the users to analyze cohorts.

Table 2.3 lists the different research questions which are answered during different research phases.

Table 2-3 List of Research Questions answered in this research

Phase of Research	RQ	Methods used
Need and Context analysis	NPQ 1: What is the meso-level information required by the stakeholders of educational dataset in their context and what is its utility?	Thematic analysis of interviews of instructors and academic staffs (N=10)
	NPQ 2: What extent existing LA tools and methods support analysis at meso-level?	Literature Analysis
	NPQ 3: What extent existing visualization is appropriate for visual analysis at meso-level?	Literature Analysis
Design & development	DQ 1: What are the constructs, methods and model of analysing the meso-level view?	Analysis of chosen scenario
	DQ 2: How can the meso-level view be represented visually?	Operationalising principles from literature
	EQ 1: How useful was the information to analyse the context?	Heuristic Analysis
	EQ 2: How usable is the designed elements (model / representation / tool)?	Heuristic Analysis
Evaluation	EQ 3: What is the utility of iSAT and how is it useful?	Case Studies (N=9)
	EQ 4: What is the perception of first time users regarding iSAT?	Quantitative analysis of surveys (TAM2, SUS) and Qualitative analysis of user statements
	What is the generalizability of iSAT?	Meta-analysis of literature

2.5 Ethical Considerations

As the evaluation cycle of this work involved human participants, we followed the following ethical considerations.

Briefing and Informed Consent: All the participants (users, collaborators or co-researchers) were briefed about the objective and the research design of the particular study they participated in. Their consent to use the data generated for our research was explicitly obtained.

Anonymity and Confidentiality: Whenever we used any data that the users of our framework / tool had collected and analyzed, we had kept their research data totally anonymized.

Chapter 3

Literature Review

This chapter provides an overview of the existing theories that inform our solution approach. From literature we provide definitions relevant to this work, existing approaches, principles and methods that are applied while developing our particular solution. Section 3.1 gives an overview of the areas which are reviewed.

3.1 Focus questions and organization of Literature Review

To understand the research landscape and existing work in analyzing educational datasets I seek answers to the following questions in this chapter:

Section 3.2: Who are the stakeholders of educational datasets?
Section 3.3: What are the purpose of analysing educational datasets?
Section 3.4: What are the strands of analytics of educational datasets?

Section 3.5: What are the models or frameworks of learning analytics?

Section 3.6: What are the methods for analysing educational datasets?

Section 3.7: What are the tools for analysing educational datasets?

The answer to these questions lay out the existing understanding of the context. The literature regarding data and information visualization that are associated with our solution approach is discussed in section 3.9. To conclude I scope our research objectives in section 3.10.

3.2 Stakeholders of educational datasets

A list of possible stakeholders in any teaching learning scenario is given below.

- Learners: Students, Online learners, Participants in workshop
- Facilitators: Instructors, Teaching assistants, Instructional Designers and Content creators
- Researchers
- Administrators: Head of the department, Head of the institution
- Policy makers: University administrators, Ministry of education

These stakeholders often involve at varied degree and focus on different kinds of insights from analyzing collected educational data. Greller & Drachsler (2012) distinguishes these stakeholders as Data Subject and Data Clients. There are specific data that are generated and gathered by each of these stakeholders (see figure 3.1 for the information flow between stakeholders). Moreover, a particular stakeholder might require specific information processed from the collected information. That information can be used to describe the context of the data or take some decisions. For instance, learner data may consist of their demographics, performance on assessments, perception responded in surveys and engagement in online activities. The instructor of a course may want to look at the information of performance records in the pre-requisite course, of the learners registered in that course. This can be used to design the level of difficulty of the introductory class.

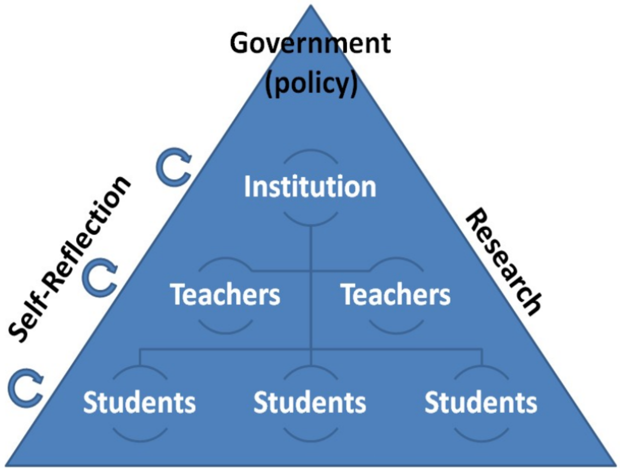


Figure 3-1 Information flow between LA stakeholders
(Greller & Drachsler, 2012)

3.3 Purpose of analyzing educational datasets

Davenport et.al. (2010), highlights six key questions that any analytics shall answer as information or insights, over any period of time (see Table 3.1). In educational context too those 6 questions are relevant from the point of view of understanding learning. Various stakeholders can utilize the answers to those questions and probably inform their decisions.

Table 3-1 Purpose of analytics (Davenport et.al., 2010)

	Past	**Present**	**Future**
Information	What happened? (reporting)	What is happening now? (alerts)	What will happen? (extrapolation)
Insight	How and Why did it happen? (modelling)	What is the next best action? (recommendation)	What's the best/worst that can happen? (prediction, optimisation)

For example, instructors may want the "reporting" of how a lesson plan worked out in the class. A learning scientist researcher can be interested in "modelling" the mechanism of learning following that lesson plan. An intelligent tutoring system logs data for "alerts" and provide specific learning scaffolds based on "recommendations". The course administration would be interested to have the insights of "prediction" in the specific teaching learning scenario.

Review studies in learning analytics compiled specific purpose and application of analytics (Dyckhoff, A. L. et.al., 2013; Park, Yeonjeong, and Il-Hyun Jo., 2015; Leitner, P., Khalil, M., & Ebner, M. 2017; Sergis, S., & Sampson, D. G. 2017). The purpose or application of analysis according to those literature is tabulated in Table 3.2.

Table 3-2 Purpose / Application of analysis of learning data

Purpose / Application of Analytics	Reference
1. Qualitative evaluation 2. Quantitative measures of use / attendance 3. Differentiation between groups of students 4. Differentiation between learning offerings 5. Data consolidation / Correlation 6. Effects on Performance	Dyckhoff, A. L., Lukarov, V., Muslim, A., Chatti, M. A., & Schroeder, U. 2013
1. to provide feedbacks on students' learning activities and performance 2. to visualize the evolution of participant relationships within discussion forums 3. to keep track of learners' interaction in e-learning systems 4. to provide a visualization of learning performance with a comparison whole class group 5. to enable students' self-reflection and awareness of what and how they are doing 6. to promote reflection and awareness of their activity 7. to improve retention and performance outcomes 8. to help students see how well they are contributing to the group 9. to improve group-work	Park, Yeonjeong, and Il-Hyun Jo., 2015
1. Predicting student performance and detecting student behaviors 2. Grouping similar materials or students based on their learning and interaction patterns 3. Detection of students with difficulties or irregular learning processes 4. Identifying relationships in learner behavior patterns and diagnosing student difficulties 5. Interpretation of the structure and relations in collaborative activities and interactions with communication tools 6. Reflecting student behavior in terms of its examination traces, consisting of a sequence of course, grade and timestamp 7. Analyzing the contents of forums, chats, web pages and documents 8. Helping instructors to visualize and analyze the ongoing activities of the students and the use of information 9. Identification of relationships among student behaviors and characteristics or contextual variables. Integration of psychometric modelling frameworks into machine-learning models 10. Include possibilities for playful learning to maintain motivation; example integration of achievements, experience points or badges as indicators of success 11. Find hidden insights in data automatically (based on models who are exposed to new data and adapt itself independently) 12. Analysis and interpretation of quantitative data for decision making	Leitner, P., Khalil, M., & Ebner, M. 2017
1. Evaluation of educational design elements based on educational data 2. Evaluation of overall Educational Design 3. Reflection on delivery of educational design	Sergis, S., & Sampson, D. G. 2017

The above listing highlights that tracing different attributes of learners during a teaching learning scenario would inform both the instructors and learners about the status of their learning activities and help to reflect on learning and teaching respectively. Researchers also analyse data for evaluating learning designs, predicting students' attributes such as performance or behaviours. In this thesis we develop a model and tools to support analysis of cohorts in educational datasets with the help of visualisation.

3.4 Strands of analysis of educational datasets

Analytics of data in the teaching learning scenario assists practitioners and other stakeholders to assess the learning scenario and take decisions for enriching the experience. The strands of educational analytics mentioned in the literature can be differentiated by their objectives and focus of analysis. Figure 3.2. gives our overview of the different strands.

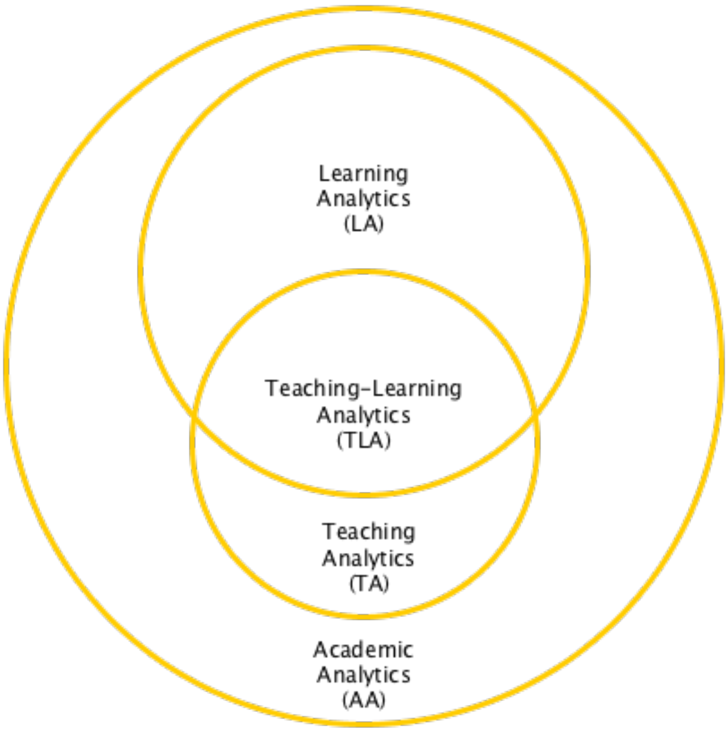


Figure 3-2 Strands of analysis of educational dataset

- Learning analytics (LA) focuses on analyzing learner's data for understanding how learning happens and to improve the experience with the insights that emerge. (for formal definitions of learning analytics see Siemens 2012, Elias 2011, Johnson et al. 2011, for learner analytics see Piety et. al. 2014)

- Teaching analytics (TA) focuses on analyzing teacher's data for teacher appraisal. (for formal definition see Gauthier, 2013; Prieto et al., 2016)
- Teaching-learning analytics (TLA) is the combined analytics to inform instructional design based on data gathered in a teaching-learning context. (Sergis, S., & Sampson, D. G. 2017)
- Academic analytics (AA) focuses on analyzing data collected in educational context to inform academic policies. (for formal definitions of academic analysis see Goldstein PJ, 2005; Ferreira SA and Andrade A 2014; for Institutional analytics see Brooks and Thayer 2016; for difference between Learning analytics, academic analytics and educational data mining see Ferguson, 2013)

In our work we want to analyze students' data generated in their learning context. Such analysis would potentially assist various stakeholders across the strands of analysis.

3.5 Models and frameworks of learning analytics

I did a basic literature search in Google scholar with two search tags, "Learning analytics models" and "Learning analytics frameworks". An illustrative list is presented here to understand the notion existing regarding model and frameworks in the learning analytics community.

An example *Model* of learning analytics is the *Reference Model* (Chatti et.al. 2013) which describe the What, Why, Who and How of analyzing learning data. Campbell & Oblinger, (2007) describes a 5-step process model of conducting analysis following Capture, Report, Predict, Act and Refine. Some of the other models highlight different aspects of LA development research, such as Mobile and Ubiquitous Learning Analytics Model (MULAM) helped to specifically analyse m-learning and u-learning environments (Aljohani N.R. & Davis H. C., 2012), another model by Wise (2014) links pedagogy and learning analytics. While these models help to conceptualize LA in a specific context or define its overall steps to process data, we didn't find any model to analyse patterns in learning data with the help of visualizations.

Similarly, *Frameworks* mostly highlight the implementation aspect of LA. For example, IRAC framework (Jones, D., Beer, C., & Clark, D. 2013) focuses on implementing LA in higher educational institutions. The LEARNSense framework (Lu, Y et.al. 2017) uses commodity wearable devices to capture learner's physical actions and accordingly infer learner context (example, student activities and engagement status in class). Such frameworks too didn't indicate the how to implement an analysis workflow which focuses on cohorts of learners in a dataset. Our work addresses this gap of a lack of any suitable model or framework to visually analyse educational datasets from the perspective of the cohorts.

3.6 Methods of analyzing educational datasets

We searched for the existing trends of the methods used in analyzing learning data. Table 3.3 highlights the distribution of those methods in published papers.

Table 3-3 Learning Analytics techniques

Technique	Number of papers	Authors
	(n=52)	Leitner, P., Khalil, M., & Ebner, M. 2017
Statistics	42 (82.7%)	
Clustering	17 (32.7%)	
Classification	11 (21.2%)	
Regression	8 (15.4%)	
Social Network Analysis	8 (15.4%)	
Association rule mining	8 (15.4%)	
Text mining	4 (7.7%)	
	(n=200)	Sergis, S., & Sampson, D. G. 2017
Prediction	36 (18%)	
Distillation of data for human judgment	33 (17%)	
Outlier detection	29 (15%)	
Discovery with models	20 (10%)	
Clustering	18 (9%)	
Social network analysis	15 (8%)	
Statistic	12 (6%)	
Machine learning	11 (6%)	
Relationship mining	10 (5%)	
Text mining	6 (3%)	
Gamification	6 (3%)	
Process mining	4 (2%)	

Readers interested in finding review regarding analytical methods, benefits, and challenges in higher education can refer to Nunn, S., Avella, J. T., Kanai, T., & Kebritchi, M. (2016). Apart from the listed techniques, we also looked into the statistical analysis techniques such as Cohort Analysis (Glenn, 2005), Time Series Analysis (Pena and Tiao, 2001) and Multivariate Analysis (Johnson R.A. and Wichern D.W., 2007). While each of those techniques respectively help to analyze groups, trace trends across time and patterns across attributes, users require that specific knowledge to contextualise and implement the analysis process in their context and gain insights regarding different aspect of the datasets. Moreover, many of these learning analytics and statistical techniques require extensive programming skills to prepare the data set for analysis and process or compute the results. This seems to be difficult for any instructors and novice researchers without such expertise.

3.7 Tools for analyzing educational datasets: Learning Analytics Dashboards

Learning Analytics Dashboards (LAD) report information regarding teaching learning context for different stakeholders. Verbert et.al. (2014) classify that LAD deployed for 3 primary contexts:

1. Dashboards that support traditional face-to-face lectures
2. Dashboards that support face-to-face group work
3. Dashboards that support awareness, reflection, sense- making, and behaviour change in online or blended learning.

Schwendimann et.al. (2017) investigated 4 research questions regarding context of the LAD, its detail, the extent of evaluation, and the open issues regarding LAD. They analysed 55 learning analytics tools. Earlier Park & Ho (2015) also analyse the intended goals of 9 existing LADs and described the visualisations that were used in it. These existing reviews of LADs indicate that researchers consider the visualisation to represent information to the users. While most of them are charts familiar to most users such as bar charts, pie charts or line charts, some of them create their own representation based on the information they depict in their dashboard. For example, SNAPP (Bakharia & Dawson, 2011) and S3 (Essa & Ayad, 2012) uses Sociogram to visualize the evolution of participant relationships within discussion forums and identify at risk students respectively. Mostly dashboards are connected to captive data sources like learning management systems or specific learning environments and represent information either at a macro level of the whole group or at a micro level regarding a single student.

Moreover, generic web-based tools for visual analytics like IBM ManyEyes (Viegas F.B. et.al., 2007), require users to upload data to server, which is often difficult with sensitive learner's data. To discuss further, we analysed to what extent the dashboards inform meso level information in Chapter 4.

3.8 Data and Information visualization

We look at the visualisation literature to motivate need for analyzing data with visualisation and inform our solution with principles of designing and interacting with visualisation. In the research context, Data visualization can serve two purposes (Shoresh and Wong,2012):

1. To communicate research finding
2. To guide the data-exploration process

In a series of column "Points of View" in Nature Methods, Shoresh and Wong (2012) focussed on data visualization techniques to support such exploration. They note "The visual display of quantitative information can help us see connections in the data. Unlike tables of numbers in which there is little visual connection between the elements, graphs allow us to easily detect data objects with similar physical properties and assemble them into a formation."

For example, Figure 3.3 describes the data table of Anscombe's quartet, which has four set of data to analyse (Anscombe, 1973). At a macro-level view, all the summary statistics like mean values of x and y, variances, correlations and regression lines are same for all the data set. But just by visualising on a scatter plot the differences in them is easily explicated. This example highlights the advantage of visualization for analysing any dataset before carrying out rigorous statistical analysis.

a

I		II		III		IV	
x	y	x	y	x	y	x	y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.10	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.10	4	5.39	19	12.5
12	10.84	12	9.13	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

b

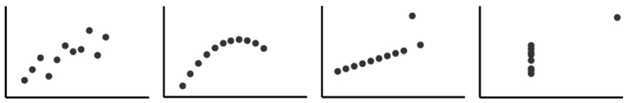


Figure 3-3 (a) The dataset and (b) scatter plot of Anscombe's quartet

3.8.1 Frameworks of information visualization

Data and information visualization research has developed various frameworks to create, analyse and understand visualizations (Card, Mackinlay, Shneiderman,1999; Chi and Riedl,1998; Munzner, 2009).

For creating a representation for the group level information, we chose the nested model for visualization design proposed by Munzner (2009). This model suits our objective to create an interactive visualization. It proposes 4 levels to consider while designing or analyzing visualisation. At the domain level, the visualisation designer considers target audience and tasks in a particular domain for which the visualisation will be created. The abstraction level indicates the mapping of problem and data vocabulary from the domain to that of the visualization. The data abstraction asks the what question, *What is shown?* while the task abstraction asks the why question, *Why is the user looking at it?* The idiom level discusses *How is it shown?;* how the visualization is drawn is the visual idiom and how the user manipulates that is the interaction idiom. The algorithm level focuses on efficient computation of the visualization.

To design our visualization, we analysed the domain and abstraction level in terms of the educational context in which the data was collected and the research questions that were asked in that context. Based on that analysis we came up with appropriate visual and interaction idiom to represent and interact with the visualisation. Details of the analysis and how is it implemented is provided in chapter 7.

3.8.2 Principles to guide visual and interaction design

The visual and interaction idiom of the artifact is informed with visual communication and interaction design principles. In visual design, Gestalt principles elaborates on the fundamental concept of grouping of visual marks. Further, Tufte's works in information visualization (Tufte, 2005) inspires various strategies for visualising quantitative information. Interaction technique taxonomies that consider interactive filtering, zooming, distortion, linking, brushing, and the like. Task taxonomies for visualization interfaces considers tasks such as overview, zooming, filtering, panning, details-on-demand, relating, history, extract, sort and comparing (Few, 2009; Heer & Shneiderman, 2012; Keim, 2002). The purpose of these filtering techniques is to remove information that is irrelevant and therefore distracting from the task at hand (Few, 2009).

We further analyse the existing visualisation that depict information regarding groups in Chapter 4 and details are provided in Appendix I.

3.9 Scoping research objective

With our research objective to conceptualise a model and tool for visual analysis of cohorts in educational datasets, we scope our research to the following -

- Strands of analytics: Though the model of meso-level analysis might be applicable across the strands we initially scoped it to learning analytics and to understand students learning.
- Stakeholders: Our primary stakeholders would be researchers and teachers. We are not focusing on understanding the utility of the model for learners themselves.
- Model: Our understanding and contribution of a model will focus on conceptualising a meso-view analysis and study its usefulness and utility.
- Purpose: The purpose of the meso-level analysis would be to understand dynamics at the granularity of cohort.
- Method / Technique: The method would enable analysing patterns with the help of visualization of the information of cohorts at a meso-level.

- Tools: To implement the model of analysis we would develop a web based open access tool.
- Visualizations: The tool would generate an interactive visualization to explore meso-level patterns.

Chapter 4

Need and Context Analysis Phase

4.1 Overview of Need and Context analysis phase

In Chapter 1, I introduced two approaches of data analysis, one at a macro level and another at a micro level. I started by clarifying the notions of macro and micro level views and analysed the scope of both of these views. Then I described how information is represented for both the levels of analysis and the limitations of the analysis tasks with such representations. This gave rise to the need for conceptualising an intermediate analysis level between the extremes of macro and micro views. We named that view the meso-level view of the data analysis. In this chapter, I identify the contexts in which need for analysing educational datasets at a meso-level arises. I interviewed instructors and academic staff to understand what students' information they collect and its utility. We contextualize this collected information from the points of view of learning analytics techniques used and how visualization methods are used to represent the information. The overview of the phase is shown in the figure 4.1.

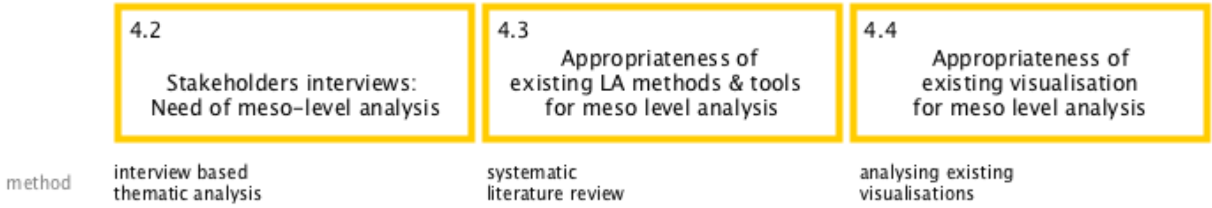


Figure 4-1 The organisation of the need and context analysis phase

4.2 Stakeholders interviews: Need for meso-level information

Experienced instructors often have an implicit sense of the different subgroups of students that exist in their class / course. So, we began by interviewing instructors in order to identify what kind of data they collect, or want to collect, to understand any sub-groups in their class. The goal was to identify the themes of utility of meso-level information.

In particular, I asked the question *What is the meso-level information required by the stakeholders of educational datasets in their context and what is its utility?* (NPQ 1). The answer to NPQ1 would help us understand the relations between the kind of queries stakeholders have and how they use the information in their context to answer those queries. This inquiry covered different learning contexts such as face-to-face classes, MOOCs and educational activities like coordination required during training workshops.

4.2.1 Methods

The participants were drawn through purposive sampling with the following selection criteria:

1. Associated with large-scale educational project which generated educational data.
2. Individual instructors interested to look at students' data collected over semesters
3. Instructors in administrative roles in colleges who required to took part in the college accreditation process.

I sought appointment for the interview from 10 screened individuals from 2 universities, IIT Bombay and Mumbai University. We conducted a semi structured interviews with 10 different teachers, educational staff and associated project researchers who spread across 5 teaching domains (Computer Science, Electrical Engineering, Educational Technology, Interaction design and Animation) and 3 Modes (Face-to-face, MOOC, Faculty development program). The Table 4.1 provides the details of the sample

Table 4-1 Distribution of interviewee sample

Teachers / Staff	Institution	F2F classroom instructor in department	MOOC Instructor / Workshop coordination
A	IIT Bombay	Electrical Engineering	Signals and Systems MOOC
B	IIT Bombay	Chemical Engineering	
C	IIT Bombay	Interaction Design	
D	IIT Bombay	Educational Technology	
E (team)	IIT Bombay		Computer Programming MOOC
F	IIT Bombay		3D modelling & animation MOOC
G	Mumbai University	Electrical Engineering	
H	Mumbai University	Electrical Engineering	
I	Mumbai University	Computer Engineering	
J (team)	IIT Bombay		Faculty development programme coordination

Each interview was between 30 and 60 mins long. The main focus questions asked was: “What information do you want to know about the learners and why?” During the interviews, participants described their context and role, the kind of learner data they look for and associated issues. We conducted Thematic analysis of the interviews to explore their range of purpose of analyzing learner data from the perspective of cohorts of learners in their context. The interviews were first transcribed before generating initial codes. Then related codes were collated into categories and themes. Finally, we reviewed the themes for consistency and refined them and created definitions. The various themes regarding what instructors wanted to understand about their learners, were based on the context of teaching learning and the educational activity.

4.2.2 Results

Broadly we identified four themes in what instructors wanted to understand about learners' data.

1. Academic performance trends among various sub-groups in the class
2. Tracing how students of certain demographic background respond to instructional interventions and/or feedback in a MOOC
3. Tracking students' classroom engagement and behaviors to modify instruction accordingly
4. Tracking extra and co-curricular activities of students

Theme 1: Academic Performance trends among various sub-groups in the class

Instructors want to understand the nature of the sub-groups that exists in their class in terms of academic performance for various purposes as described by our participants. For instance, Par G reported that Mumbai University has recently made it mandatory for college accreditation to trace performance of students across time. In the process of organising data for the accreditation, the teachers are required to group students in different competency levels based on their test performance in each course.

One instructor (Par H.) wanted to trace performance transitions across batches. For instance, Par H had performance data for 3 batches (2012-14) on a course and wanted to map the instructional strategy that was used in the course and the distribution of performance in each year. Par H believed tracking both the instructional strategy and assessment performance would help redesign the course.

Another instructor (Par C.) wanted to track students' performance across different types of courses, for instance in an offered elective and its prerequisite course(s). Par C believed knowing the performance of the students in the pre-requisite course would help to strategize how to introduce the current content for that batch. Likewise, understanding transitions of performance across foundation courses and capstone course might help while reorganising curriculum at the departmental level.

For academic coordination, tracking students' performance is required in face to face classrooms, MOOCs as well as professional development workshops. Par J pointed that staffs require to coordinate and send personalised emails to specific groups of performers and support their learning. Hence identifying the groups of performers in a set of enrolled learners is an essential activity. This information would also be useful for preparing comparative reports of re-runs of the offered courses.

Theme 2: Tracing how students of certain demographic background respond to instructional interventions and/or feedback in a MOOC

I interviewed 2 different MOOC instructors who were offering courses on 3D Modelling and Animation and Signals and Systems respectively. In addition, I interviewed two TAs who were handling the Computer programming MOOC. MOOCs have varied demographics of participants. Both the Par F and the Par E wanted to know the distribution of the online learners who enrolled and their corresponding occupation. For the animation MOOC, the instructor had prepared a specific entry survey to get what proportion of students were already in the animation industry, or planning to switch jobs, or interested in animation in general. He set the discussion forum activities based on this information. Similarly, in the CS MOOC there were participants who were already in jobs and revising programming concepts, students from other colleges getting credits on the course and general learners who want to learn programming. The TAs wanted to know about the student's profile to provide specific feedback to each sub-group of learners.

Theme 3: Tracking student's classroom engagement and behaviours to modify instruction accordingly

In face to face classroom, teachers want to track the academic engagement of students. The observed students' behaviours can serve as a cue for the instructor to decide whether to continue or change their instructional strategy. Often such cues are perceived implicitly by the teacher and it becomes difficult to point out which parameters to track. But the instructors gave us some pointers towards what external behaviours they wanted to track.

Instructor (Par A) reported that "I might see certain students respond actively in the class and some don't, they might just not be willing to respond ... some people are passive in the class but otherwise understood the material and can respond reasonable in the exam, some people can do neither. What is it that distinguish between them and what can be done to move the third category to one of the other two categories?”

The instructor was also interested to track the in-class questions that the students asked. During classroom lectures there is certain contextual information, for example “there are specific examples being discussed, the questions can pertain to them, or student may ask a specific step in the derivation”. Tracking these questions gives feedback to the instructor regarding the status of understanding of the students in that session. Par A also wanted to gauge the level of the class in terms of student’s understanding of the topic and how well they can apply the concepts learnt during any course or after any chapter. It is believed all of this information would essentially identify sub groups of learners and assist in strategizing the instructional strategy.

In another context the instructor wanted to track change in learning behaviours near the examination and the possibility of grouping students based on it. Specifically, he was interested in knowing “Are exams a trigger for learning? That is an important question. To some extent it is bound to be, are they the only trigger for learning - so the regularity with which one learns material and extent to which one crowds learning towards the exam time.”

MOOC instructors also wanted to gauge the engagement of the students and their performance across the various components of the course. Engagement of learners over a period of time to understand consistency. Learner related data indicating usefulness of content or pedagogical activities to cater to a high student diversity learning scenario.

Theme 4: Tracking extra and co-curricular activities of students across time

The accreditation process also required tracking information regarding the alumni as mandated by the Mumbai University (Par G.). Additionally, Par C. also wanted to know how many students pursued their own discipline after they graduate and in a class of 60-70 students, how many went for an industry job, how many are satisfied and if not, what is the reason. Par H. believes this information is useful to counsel upcoming batches of students.

4.2.3 Discussion

The thematic analysis revealed the requirements of the instructors and academic staff at a meso-level and where they want the perspective of cohorts existing in their scenario of teaching-learning. Four themes emerged from the analysis: i) Academic performance trends among various sub-groups in the class, ii) Tracing how students of certain demographic background respond to instructional interventions and/or feedback in a MOOC, iii) Tracking students' classroom engagement and behaviors to modify instruction accordingly, iv) Tracking extra and co-curricular activities of students.

There were similarities of requirement from face to face and MOOC instructors. For instance, all instructors desired to track performance of students. Additionally, some instructors wanted to know about affective factors such as engagement behaviors of their students in order to counsel them. Further, there are differences in the kind of questions instructors ask across the period of the course, for example, at the beginning of a course an instructor wished to know more about the prior knowledge level of the students and at the end of the course he/she may want to know perception of learning for specific student cohorts such as students who have taken the course as elective or ones who are low performers. However, the instructors conducting face to face classes that we interviewed didn't elaborate any requirement of sub-groups information specific to their course content / area of subject they are teaching. Recent work (Knight, D. B., Brozina, C., & Novoselich, B.,2016) also analysed the perception of learning analytics from the point of view of the freshmen engineering students and their instructors. But we found no literature focusing on the need of information regarding sub groups of students. In particular, based on the themes that emerged we find that there is a requirement of tracking the sub-groups to find difference across time or across different attributes.

4.3 Appropriateness of existing LA techniques & tools for meso-level analysis

Our earlier empirical study found the need of tracing transitions of different sub groups in various teaching learning scenarios. In this section, I look at the existing learning analytics techniques and dashboards and to what extent they support instructors or researchers to analyze cohorts and report the findings with the help of a visualization. Specifically, I ask two questions to establish the need for and position the research.

NPQ 2a: To what extent do existing LA techniques support analysis at meso-level?
NPQ 2b: To what extent do learning dashboards assist analysis at the meso-level?

4.3.1 Methods

To answer both NPQ 2a and 2b, I performed literature review of techniques and tools from review papers. 16 LA techniques were analysed from 2 review papers. Data regarding 55 Learning Analytics Dashboards (LAD) were collated from 3 review papers. To answer NPQ 2a, each of the techniques and tools was categorized according to three criteria namely,

1. Does it provide information at meso-level?
2. Does it track records for analysis or does it have transition information across attributes?
3. Is it supported with visualization?

We did a meta-analysis of the reviewed literature on learning dashboards to find the answers to NPQ 2b. The intended goal of the dashboard was categorized based on whether it focuses on individual learner (micro level), the whole group of learners like a class of students (macro level) or a sub- group in the class (meso-level).

4.3.2 Results

Among the 16 techniques gathered from literature review, I found 5 fit to our criteria. While Clustering and Classification techniques highlight sub-groups, they don't track any sort of attributes of those sub-groups. The results of those algorithm can be visualised by scatter plots. Similarly, Association Rule Mining and Outlier detection techniques also aggregate information regarding a specific group but any information regarding their transition is not focused during analysis. Social network analysis often visualizes individuals in the network as a node in a graph and track connections via link. But the notion of cohort of those individuals are not directly analysed by such visualisation. Table 4.2 presents a summary of the analysis.

Table 4-2 Techniques used for meso-level analysis

Techniques	Cohort information	Tracking information	Possible data representation
Clustering	Yes	No	Scatter Plot (see Hinneburg, A. 2009 for other techniques such as heatmaps and dendograms)
Classification	Yes	No	Scatter Plot
Association Rule Mining	Yes	No	Grouped matrix based visualisation (Hahsler, M., & Karpienko, R. 2017).
Outlier detection	Yes	No	Scatter Plot, Histograms
Social Net Analysis	No	Yes	Node and Link graph (see Crnovrsanin, T. et.al. 2014 for review)

Next, I analysed 23 LADs which use visualization to highlight patterns existing in analysed data. Table 4.3 presents the list. While most of the LADs present aggregated information at a macro level for the instructors and administrator to analyse, ones which has learner interface also provides micro-level views for the learners. The meso level view often highlights information only regarding predefined groups of students, for example the project group which is working on the virtual lab (WebLab Duesto) or a table top environment (NaviSurface). Some dashboards assist exploratory analysis of cohorts for example to find at-risk student (Course Signal) or learner types in ubiquitous mobile learning environment (SCROLL).

Table 4-3 Learning Dashboards and level of analysis that they support

Tool / Dashboard name	Level of analysis	comment
eLAT	Macro	exploratory learning analytics tool for reflection and iterative improvement of technology enhanced learning.
EVADE	Macro	Visualizes the distribution of a whole class with doughnut chart
STEMscopes	Macro	Whole class visualisation with colour coding for increase or decrease in grades
Graasp	Micro, Macro	Associated with the GoLabs learning environment
ALAS-KA	Micro , Macro	Visualizations based on learning patterns and performance useful for teacher and students
WebLab Duesto	Meso, Macro	Visualizes results of virtual labs
Collaid	Meso, Macro	Tabletop Supportive Collaborative Learning
Course Signal	Macro, Meso	Identify at risk students
MQAS	Micro	The feedback provided to students and teacher was in terms of grades
Next-TELL	Micro	Next-TELL IOLM can take a range of sources of data for visualisation to the learner.
My Grades within LMS Blackboard	Micro	The feedback provided to students and teacher was in terms of grades
eMUSE	Micro	Learning through social connection or peers
SLAR	Micro	Learner behavior in virtual mode
SCALA	Micro	Usage and interaction of learner
LIM App	Micro	Feedback for lecturer/presenter
GradeCraft	Micro, Macro	Talks about how successfully assignments are completed by students individually and the class as a whole across a structured grading rubric.
Student Explorer	Micro, Macro	visualized individual list of students who need attention and has class level values for comparison
moocRP	Micro, Macro	Focuses on Learning pattern and engagement
Different Next-TELL tools like OLM	Micro, Meso	Discussion visualizations for teachers, response time
Navi Badgeboard, Navi Surface	Micro, Meso	Both individual and group activity can be visualized, but also data on interaction between students, groups and even interaction with external people is available.
LARAe	Micro, Meso	LARAe teacher dashboard provides a detailed overview of group and individual activities, achievements and course outcomes.
EngAGe	Micro, Meso	Micro - Individual student progress comparison Meso - Learning curve by gender, who played game by age
SCROLL	Micro, Meso and Macro	Framework to support and share ubiquitous learning log in the context of language learning.

4.3.3 Discussion

Verbert et.al (2014) proposed an LA process model where the dashboard supports stakeholders' awareness, reflection, sense making and consequently impact. For researchers the impact is in the insights and the new meaning that emerge out of the visualization of their particular study. But our above analysis shows that most of the tools developed were associated with a captive data source like Learning Management System (LMS), or MOOCs platform. Romero and Ventura, (2007) also found 23 out of the 24 dashboards that they reviewed, essentially tracked data through captive logs of the application to which they were linked. The tools do not allow users to upload, visualize or interact with their own datasets independently. Further, the survey of the LADs highlights that there are very few tools which analyse and visualise sub-group level data. Even the ones which provide group level information mostly do clustering and don't do track of clusters. Moreover, the learning dashboards have specific data type and analysis method which doesn't allow users to adopt their analysis method for different types of data or vice-versa. For example, the methods used for analyzing students' interaction is not possible to analyse any other attributes.

This prompted us to develop a method which can be independently applied by the users to their dataset and interpret the resulted information in their specific context.

4.4 Appropriateness of existing visualization for meso-level analysis

Users in different domains already visualize group level information for analysis and reporting. Here I discuss some representative visualizations that convey data regarding a group in order to understand whether these may be appropriate and applicable for meso-level analysis of educational data. In order to identify the existing visualizations available that convey information regarding subgroups and transitions we investigated *To what extent is existing visualization appropriate for visual analysis at meso-level?* (NPQ3).

4.4.1 Methods

I did an analysis of three online visualization catalogues, the details of which are given in the Table 4.4.

Table 4-4 Online visualization catalogues

Catalogue	**Number of listed visualizations**
http://www.datavizcatalogue.com/index.html	60
http://survey.timeviz.net/	115
http://www.visual-literacy.org/periodic_table/periodic_table.html (Lengler & Eppler, 2007)	100

Within these catalogues, the selection criteria of visualisation were the ones that conveyed information regarding sub group of data within a larger dataset. A representative sample of 7 visualizations were selected. They are Histogram, Parallel coordinate plot, Sankey diagram, Circular plot, Stream graph, Alluvial diagram, Parallel sets. I evaluated the utility of these visualizations for representing the meso-level information of transitions of cohorts. In the process I also highlight the features to focus on for the analysing a meso-level visualisation. Based on the data gathered from literature regarding these visualizations, I noted the domain in which the visualization was used, how categories were indicated as visual metaphors, whether it encodes frequency information, whether it handles multiple attributes, whether it visualises transitions across time or attributes, and whether there are tools built to facilitate users.

4.4.2 Results

The results of the analysis are described in Table 4.5. The detailed description of each of the visualizations is presented in Appendix I.

Table 4-5 Comparing different visualizations depicting a group or transitions.

Features	**Histogram**	**Parallel Coordinate**	**Sankey Diagram**	**Circular Plot**	**Steam Graph**	**Alluvial Diagram**	**Parallel Set**
Relevant Publication	Ioannidis, Y, 2003 gives a historical perspective	Inselberg, 1985;2009	Riehmann, P. Hanfler, M. & Froehlich B. 2005	Abel, G. J., & Sander, N. 2014	Havre, Hetzler & Nowell, 2002	Rosvall & Bergstrom, 2010	Kosara, R., Bendix, F., & Hauser, H. (2006).
Domain of described example	-		Energy flow	migration of population	analysing communication content	transitions in domain of practice to neuroscience	CRM dataset and comparing housing data from 2 US states
How to represent category data	different set of bars differentiated by colour	by giving nominal numeric values to the different categories	category is only with respect to the different sinks of the flow	making each segment as a different category	each new stream is another category	each new band is a new category	each horizontal segment is a category
Shows frequencies	✓	no	✓	✓	✓	✓	✓
Handles multiple attributes	✓	✓	no	no	no	no	✓
Can represent transitions across multiple attributes	no	✓	no	don't know	no	don't know	✓
Can represent transitions across time	no	✓	no	no	✓	✓	✓
Web based Interactive tools	https://plot.ly	no	no	http://mkweb.bcgsc.ca/tableviewer/	no	no	no

4.4.3 Discussion

Domain of described example of visualisation: Some of the selected research papers gave illustration of the visualization in a specific context. For instance, Sankey diagram was used to describe and compare energy flow in a system and it indicated the loss of energy after any particular phase or component in the system. Circular plot was used to visualise the migration patterns of population. Alluvial diagram visualised transition of 7000 citation patterns from different disciplines to the domain of practice to neuroscience, highlighting its emergence from interdisciplinary speciality to a mature discipline of its own. Using Parallel Set a multi attribute customer relationship data was visualised for explanation of the analysis. None of these visualisations were created or conceptualised from the context of educational data analysis though.

Representation of category data: The notion of categories were executed differently in each visualization. The histogram has each of the bars representing a category. At times colouring the bars would also indicate aggregation of those sub-categorisations. In parallel coordinates, each coordinate axis represents a different attribute of the data and each record is visualised as a separate line connecting its values on the axis. Categorisation can be done by either designating another axis which has nominal values of the categories or colouring lines representing a group of records. For Sankey diagrams, in the context of energy flow visualization, categories are mostly limited to understanding different types of energy sinks. In circular plot, there are different segments which can convey different categories. In stream graphs each stream denotes a different category. Similarly, in Alluvial diagrams each new band is a new category. In parallel sets each horizontal segment conveys a category. This analysis helped us while we designed our visualisation to convey categories, its frequencies and transition patterns.

Most of the selected visualizations, apart from Parallel Coordinates, visually encode information regarding frequencies of the number of records in any category. Sankey diagrams, Circular plots Steam graphs and Alluvial Diagrams encode only one global attribute whereas histograms, parallel coordinates and parallel sets can encode data with multiple attributes

In the context of education, some researchers have created their own visualizations for the purpose of reporting the transitions. One example is the distribution of students' answers across voting phases of peer instruction activities (Wittmann, M. C. and & Black, K. E. 2014). However, it doesn't support interactive exploration of patterns that exists in the data. Similarly, another academic administration tool http://connections.tgs.northwestern.edu/flow uses interactive visualization to highlight trends of students registering for different graduate courses. They trace which PhD program students come from and which program do they take courses in. These information visualizations are linked to only one dataset and does not afford any specific exploration of the patterns in such transitions. Also, the tools for data visualisation are mostly proprietary desktop applications. Current data visualisation libraries like GGPlot2 exists for free analysis software like R and D3 for the web but they require the users have competency in coding to create their own visualisation and analyse them.

4.5 Synthesizing initial design and development goals

The answers to the three sets of research questions highlights a need for conceptualization of a model for visual analytics of cohorts, that instructors and educational researchers can use. The current research aims to bridge this need by conceptualising a meso-level analysis model based on transitions across attributes. While certain methods and techniques do exist in LA to stratify data, they don't track the sub-groups (for example, clustering), certain visualizations depict transitions without a specific sense of strata. Visual cohort analysis tools have been developed for healthcare applications (Zhang, Z., Gotz, D., & Perer, A.,2014; Perer, A., Wang, F., & Hu, J., 2015; Krause, J., Perer, A., & Stavropoulos, H. 2016), but to our knowledge there is no evidence of transitions in learning data being visualized. Thus, our objectives to conceptualise the meso-level analytics are,

- Specifying the criteria of the scenario for which data is analysed,
- Develop methods to process and interpret the data,
- Design a visual representation to interact and report the insights.

This scope of development also highlights the specific evaluation that could be done namely,

- Evaluate the usefulness of the meso-level information in the context of its use.
- Evaluate the usability of the methods and representations for the meso-level analysis.

Chapter 5

Design and Development Phase - Stage 1: Genesis

In the need and context analysis we found that though instructors and researchers were interested to identify specific cohorts of students and track them, they were often limited by methods and tools. The existing learning analytics methods and tools do not explicitly prescribe data visualization-based approach to conduct analysis and reporting of sub groups of students. While Learning Analytics Dashboards (LADs) visualise information regarding teaching learning scenarios for its users, but often such LADs operate on captive data sources like a specific TEL environment or LMS. Users cannot process their own data from other sources in such dashboards and interoperability remains an issue.

With this understanding, I started the next design and development phase. I aimed to bridge the gap by creating a model of visual analysis to analyse cohort level information and developing an open access tool to assist both researchers and teachers to visualise their own dataset and gain insights.

5.1 Overview of the Design and Development Phase

The design and development phase had iterative stages of design of the meso-level analysis model and development of a tool to support it. Our particular work involved three stages. In the first stage we focused on the genesis of the concept of analysing cohorts at a meso-level, in the second stage we refined that concept and in the third stage we implemented a visualization tool based on the developed model of meso-level analysis. In each stage we carried out steps to understand the design objectives or analyse problems listed from previous stage, then apply existing knowledge to build a solution and formatively evaluate it. Over the three stages we created the constructs, methods, visual representations and a web-based tool. Figure 5.1 gives the overview of the three stages of the design and development phase.

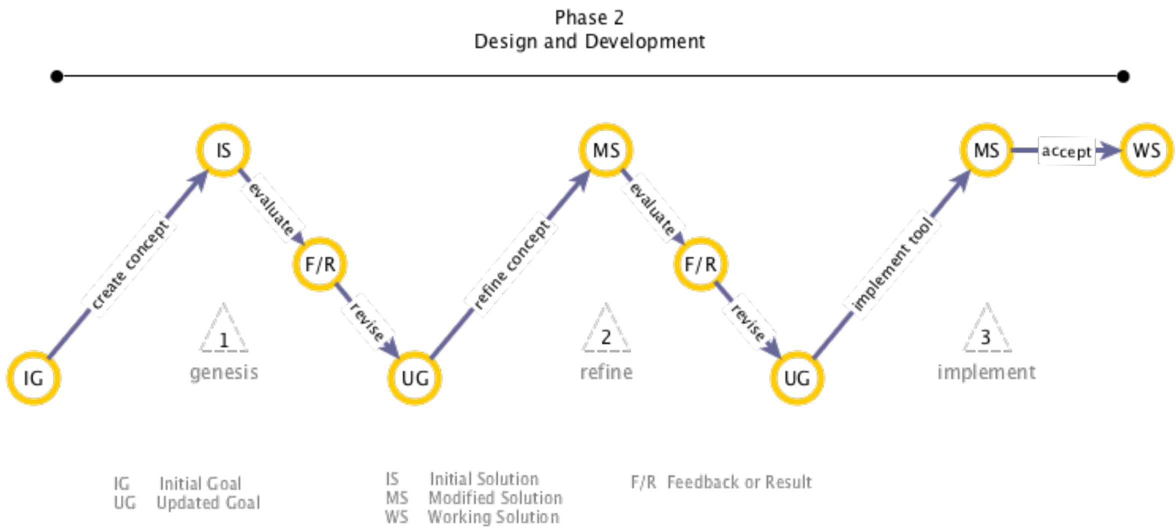


Figure 5-1 Overview of the Design and Development Phase

In this chapter we discuss the genesis stage. We develop the concepts of meso-level analysis based on tracing transition of sub groups. Such transitions can be studied across time or across attributes. In the first iteration we studied temporal transition in datasets.

5.2 Genesis stage: goals and objectives

In the genesis stage our goal was to select a real-world analysis scenario where data was collected across multiple instances of time. Based on that collected data we aimed to generate a meso-level view regarding different cohorts that exists in that context. This involved developing an information artifact by defining constructs of analysis, methods of data transformation and its interpretation. We wanted to further generate a visual representation of that meso-level information to assist this analysis. We aimed to develop a descriptive model of analysis at the meso-level in a specific context and then study the insights that was gathered in that context and understand its generalisability. We considered researchers as our primary users.

5.3 Selected context: Tracing Student's Engagement in large classroom

The illustrative context for this stage is a specific study in a large undergraduate CS101 class. The instructor of the course implemented multiple sessions of Think-Pair-Share (TPS), a three-phase active learning strategy. One of the objective of that study was to understand variation in student engagement level during three phases of the activity. This study initiated the first genesis stage.

Research objective of that specific study

The research objective of our study was to investigate engagement during TPS activity in a large-attendance classroom. The relevant research questions were:

1. How much student engagement occurs during the TPS activity?
2. How does the amount of engagement change as activity progresses?

Dataset

To determine student engagement, we did 2 pilot runs to develop a real-time classroom observation protocol. The protocol listed 17 possible behaviours that the learner does during the TPS activity. We sampled students randomly from across the class. Then 2 trained observers observed the behaviour for those sampled students across each of the think, pair and share phases of the TPS activity. We collected data regarding 228 students across 5 implementations of TPS activities. This data was selected to analyse the engagement patterns. Interested readers can look at Kothiyal et.al. (2013) for further details regarding the study.

Analysis

We initially looked at the macro and micro level analysis that was possible in that context. The collected raw data had observed behaviour of the students. From the macro level perspective, we aggregated all the behaviors observed in each phase (Think, Pair and Share) of the activity (see Fig. 5.2). The pie chart representation indicates the proportion of the observed behaviors. The users can compare proportions within each phase, for example the largest pie in the Think Phase is "Writing in notebook" (47%) which highlights the most prominent behaviour observed in the corresponding phase. They can also compare two pie charts to find the relative proportions of the behaviour. For instance, "Writing in notebook" is observed 47%, 23% and 10% of the time in the Think, Pair and Share phase respectively.

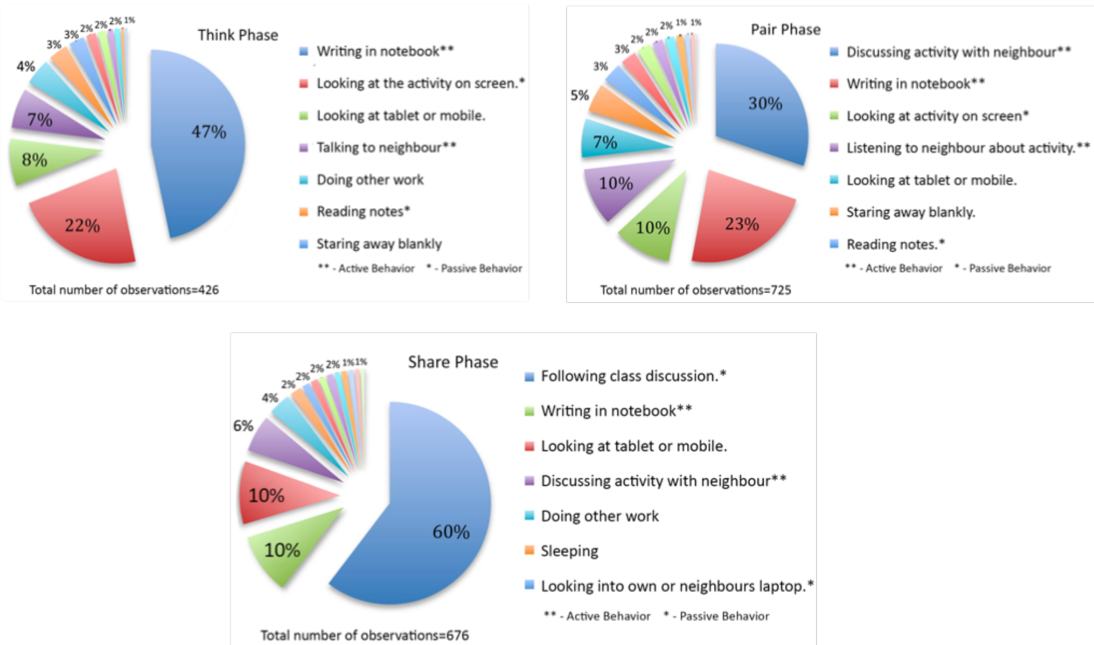


Figure 5-2 Distribution of observed behaviours. (Kothiyal et.al. 2013)

Next analysis was from the point of view of a single observed student. A criterion was defined to rate engagement level of each student based on their observed behaviour type in each phase of TPS activity. For example, "writing" indicated desired engaged behaviour in the Think phase but “talking to neighbour” was undesired during the same phase. But during Pair phase “talking to neighbour” was classified as an engaged behaviour. We observed each student multiple times across a particular phase. Their engagement in each phase was binned into four levels - Always engaged, Mostly engaged, Sometimes engaged and Never engaged. The raw observation data collected in a spreadsheet can be visualized by highlighting the cell corresponding to the type of behaviour. At least 3 observation instances of an individual student were compiled to decide the level of engagement in each phase. An illustrative example of such a spreadsheet is given in Figure 5.3.

Student number	**Think Phase**				**Pair Phase**		**Share Phase**
	Ob. 1	**Ob. 2**	**Ob. 3**	**State**	**Ob. 1**	**Ob. 2**	**…**
Student 1	Writing in notebook	Writing in notebook	Reading notes	Fully Engaged	Discussing with neighbor	…	
Student 2	Reading notes	Looking at tablet	Looking at screen	Mostly Engaged	…		
Student 3	Doing other work	Doing other work	Staring away	Never Engaged			

Figure 5-3 Example of spreadsheet analysis

Lastly at the class level, the behaviours were aggregated across 5 field observations of TPS in large classroom. This provided the macro view of the engagement level of the class in each phase of TPS across the semester. Figure 5.4 presents the bar chart highlighting the proportion of different engagement level in each phase.

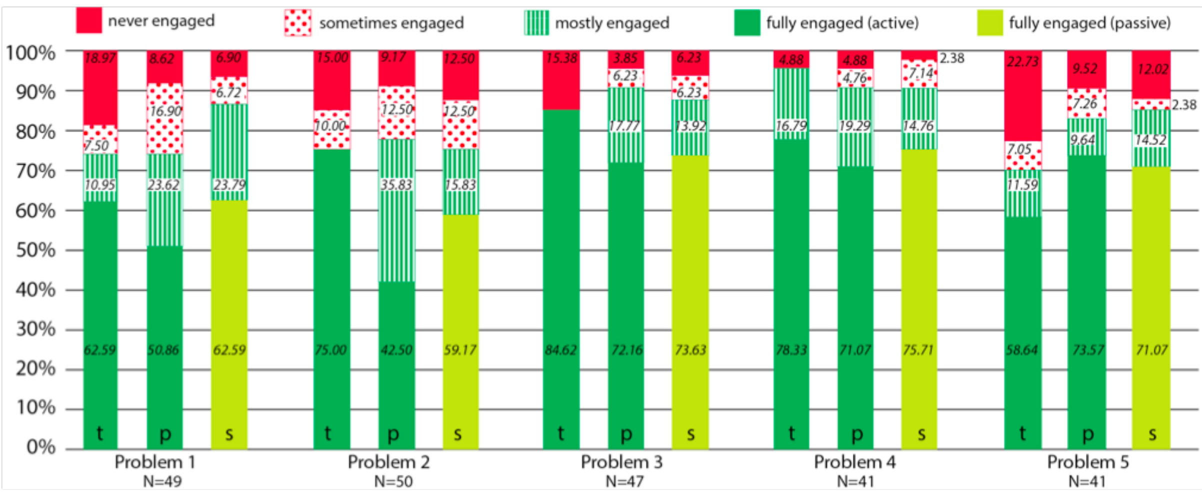


Figure 5-4 Overall observed engagement for each TPS session. (Kothiyal et.al. 2013)

But none of the above analysis would answer queries such as what proportion of the students were initially disengaged during think phase but then gets to engage state during pair phase? Is the proportion of the group who are becoming engaged during pair phase more than the cohort which never engages? What proportion of the students remain in the same state of engagement across the three phases? Such queries would help to develop an empirical model of the students' behaviour during the TPS activity.

5.4 Genesis of Meso-level analysis

5.4.1 Approach to develop information artifact

To conceptualise an information artifact that will assist analysis of cohorts in the specific context of the TPS study we defined its *Construct*s and *Methods* (Henver et.al., 2004). Our approach was to consider every phase of the activity and define level of engagement as a state based on the observed students' behaviour. The analysis would enable tracing probability of transition between those engagement states from one phase of the activity to the next. To assist the analysis, we created a diagrammatic representation to convey the information regarding transitions between engagement level across the phases of the activity.

5.4.2 Designed constructs and visual representation of the meso-level view

For ease of understanding, I first illustrate the constructs in the context of the TPS engagement study and then give their formal definitions.

While studying engagement in TPS, each of the Think, Pair and Share phase of activity were considered as *Phases*. In each phase, *States* of engagement were defined in terms of the collected data. *Transitions* from one state to another across consecutive phases indicate the proportion of the students who transit between those two states. The probability of that transition is the *Transition ratio*.

Figure 5.5 shows the State Transition Diagram that represents the meso-level information visually. The circles represented the *State* of engagement and a set of vertically aligned circle indicated a specific *Phase* of TPS. For example, the left stack of circles represents the *Think phase* with the top green circle as the *Fully Engaged state*. The text in the circle conveys that the corresponding state has 164 observations, which is 71.83% of the total observations in Think phase. The links represent the *Transitions* across states of two different phases. The box on the path of each link conveys the *Transition ratio* to the corresponding linking strata. In figure 5.5, 68% (transition ratio) of the 164 records in Fully Engaged state transit to the same stratum in the next Pair phase.

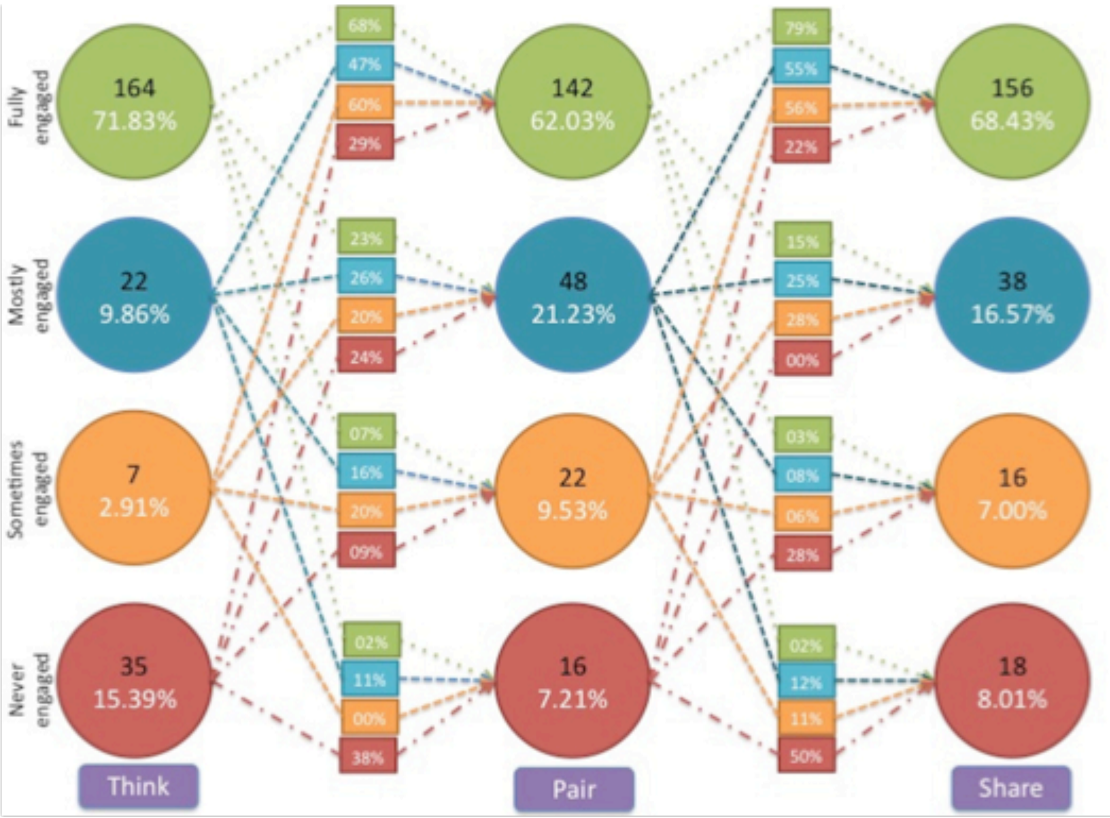


Figure 5-5 The transition pattern of engagement during TPS activities. (Kothiyal et.al. 2013)

The formal definitions of the constructs developed in the genesis stage are given in Table 5.1.

Table 5-1 Constructs developed in Genesis stage

Constructs	What does it define	Example
Phase	Any instance of time where an attribute is collected can be represented as a phase	Engagement during the Think phase can be represented as a phase
States	The specific groups defined by criteria set on attribute values defines states	With engagement level as attribute and 'Highly Engaged' is a state.
Transitions	The migration of cohort from one state to another is represented as transition	Across different phases of activities, transition can represent the proportion of the Never Engaged who become Highly Engaged.
Transition ratio (TR)	TR for a particular transition is the ratio of the number of records which migrate in that particular transition to the number of records in the state from which it migrates in the previous phase	If 20 students were in Never Engaged in Think Phase and 5 of them migrates to Highly Engaged level then the TR for that Never - Highly engaged transition is 0.25 (25%)

5.4.3 Developed methods for meso-level analysis

A four-step process was developed to setup, compute, represent and interpret the meso-level information (see figure 5.6).

1. In Setup and Pre-processing step, one first determines the Phases and States in the given context. Based on the research context, one defines criteria to group records into States. For example, in the context of engagement study, each phase of the activity (Think, Pair and Share) was our phase and we defined 'Fully Engaged' as a stratum that represents records that have all the observed behaviors coded as 'engaged'.

2. In the Label and Count step, one computes proportion of records in each stratum and note their transition ratio. With our TPS observation data we used spreadsheet calculations to first compute the proportion of records in each engagement level and then the transition ratio of records which moved across engagement states between the phases.

3. In the Represent step one creates a transition map, a visualization to represent the information regarding phases and states in each phase. The corresponding computed values (numbers, proportions and transition ratios) are populated in that map.

4. In the Inference step one analyses the transition map for describing temporal insights regarding the context in which the data was collected.

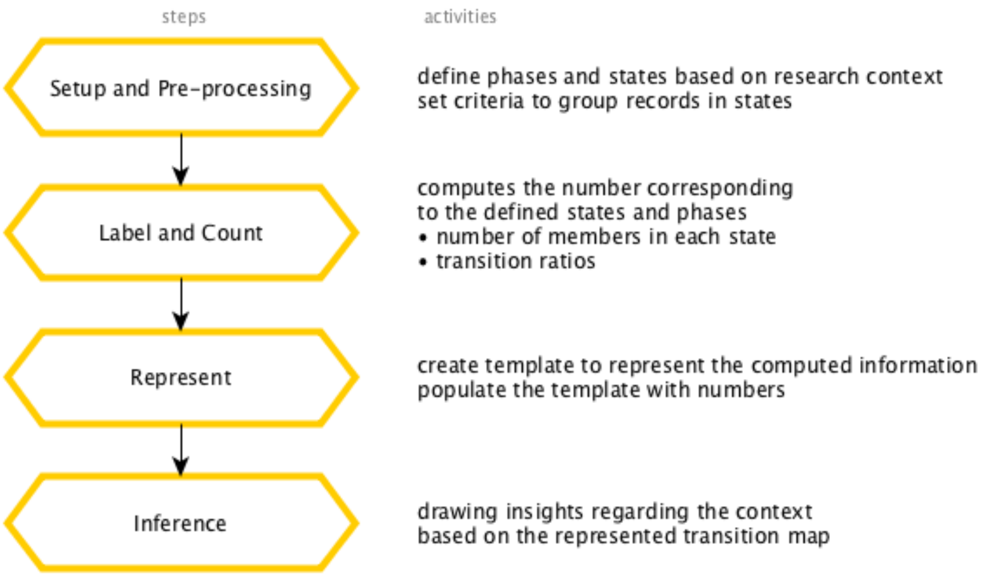


Figure 5-6 The methods developed in Genesis stage

5.4.4 Model of meso-level analysis

A descriptive model of meso-level analysis describes how the different constructs and methods are related. Figure 5.7 describes the model developed in this genesis stage.

Given a context where temporal data is collected, user can choose each time instance as a Phase and define attribute levels to specific States. Transitions between states of different phases are defined by computing Transition ratio of number of records that move between those corresponding states to the one in the initial state. The information regarding the Phases, States and Transitions are then visualized as a State Transition Diagram. To analyse the meso-level view, the user reports the transition ratios of the transition of interest in the context or the one prominent in the collected dataset. The analysis helps user to explicate patterns of transitions and investigate temporal trends for different sub-groups in the context.

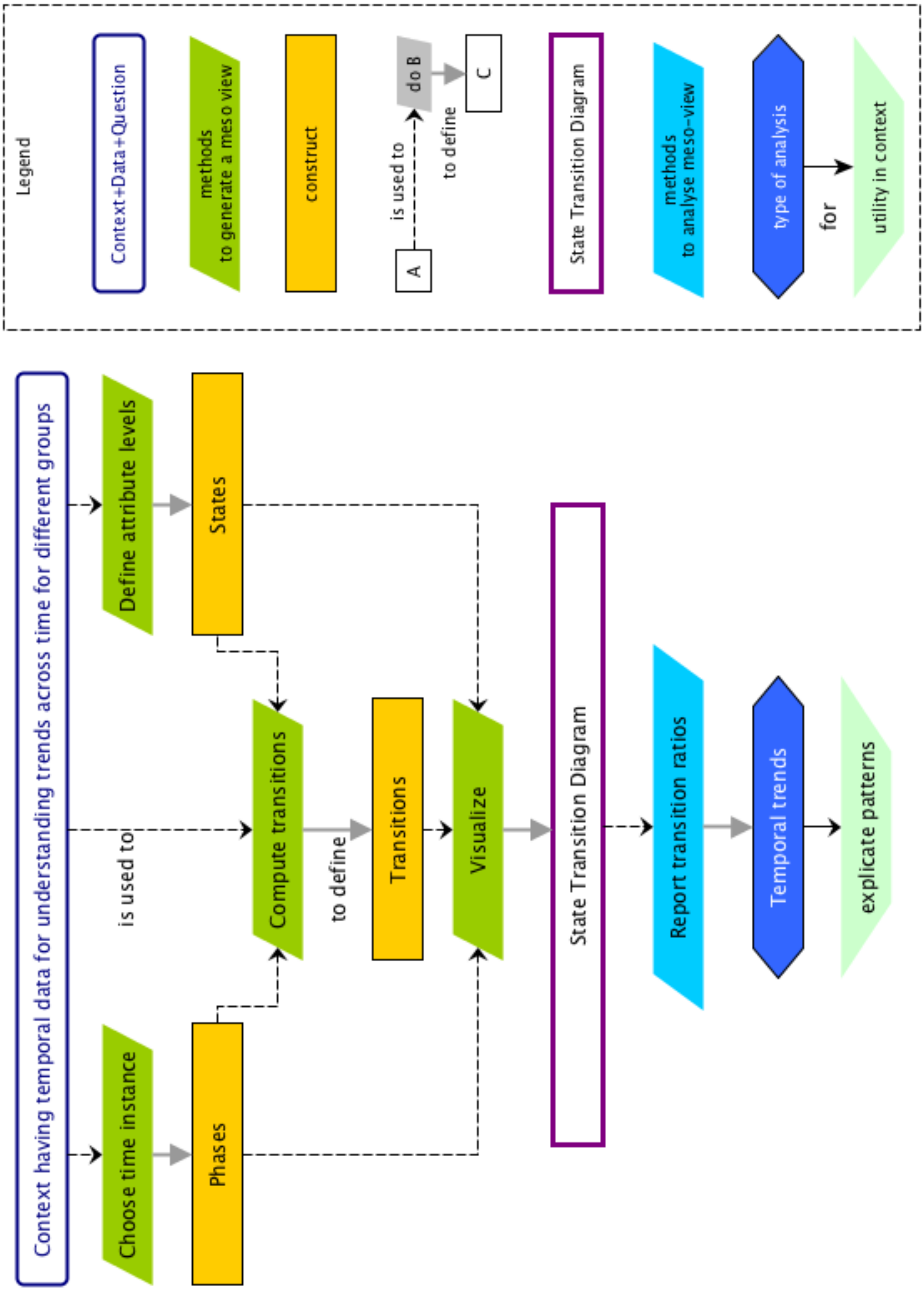


Figure 5-7 Descriptive model of the constructs and methods developed (Genesis Stage)

5.5 Initial concept and workflow of meso-level analysis

The model, constructs, methods and visualization of the artifact generated in the genesis cycle is summarized in Table 5.2.

Table 5-2 Developed meso-level information artifact during genesis phase

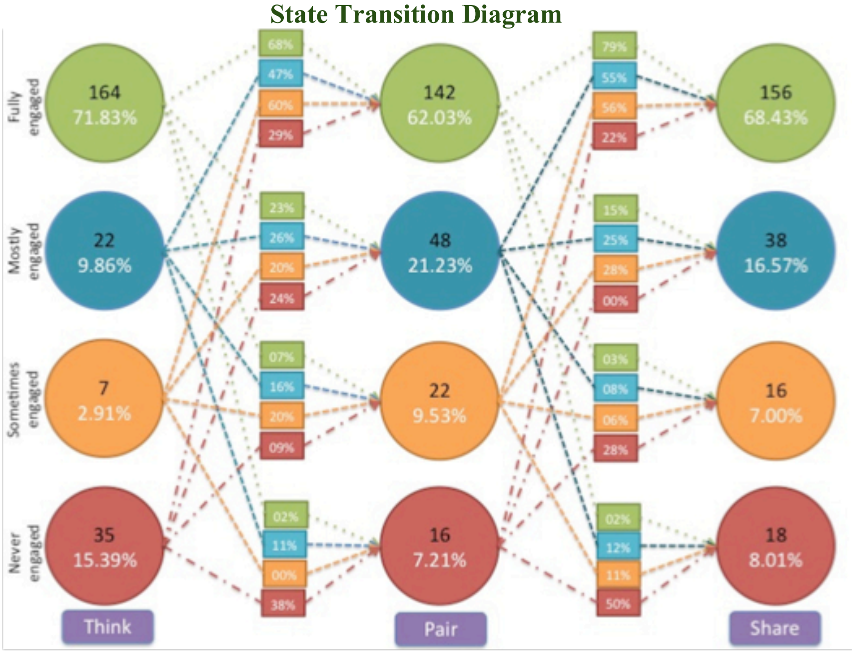
<table>
<tr><td>Model</td><td>Model to trace transition across time.</td></tr>
<tr><td>Construct</td><td>State, Phase, Transitions, Transition ratios</td></tr>
<tr><td>Method</td><td>Developed a method to generate and analyse temporal transitions in a dataset from a meso-level view.</td></tr>
<tr><td>Representation</td><td>State Transition Diagram

</td></tr>
</table>

Figure 5.8 presents the meso-level analysis workflow developed at the end of first genesis stage. Given any user's context, their collected datasets and initial set of queries or research questions users can apply the methods to generate information regarding the meso-level view. Users can visualise this meso level view as a State Transition Diagram. They can analyse the diagram to trace information regarding the proportion of each state in a phase and transition ratio between phases to indicate temporal trends and insights.

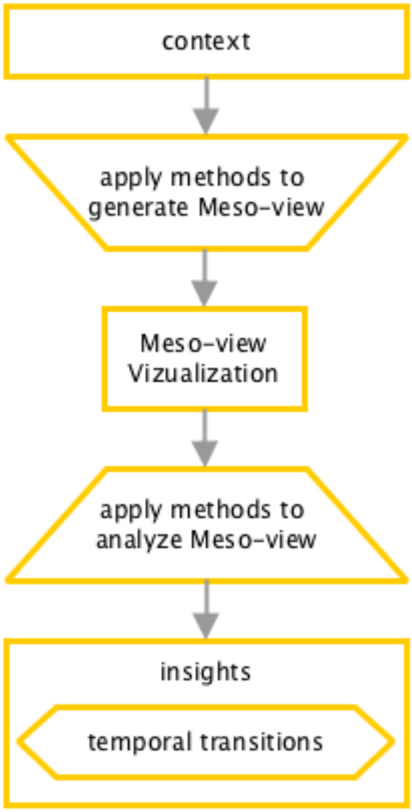


Figure 5-8 The Meso-level analysis workflow (Genesis stage)

5.6 Evaluation and findings of the genesis stage

I evaluated the created model of analysis based on its application in the context of analyzing students' engagement during TPS activity.

5.6.1 Methods

To answer, *How useful was the meso-level information to analyse the context?*, I analysed the regular group discussions with the other 3 researchers involved in the study and the reported conference paper of the study (Kothiyal et.al. 2013). I looked at the generated meso-level information related to the cohorts of students and what it highlighted regarding their transitions of engagement states. This perspective of meso-level view of the transition of states was contrasted with aggregating behavioural observations (macro-level view) or tracing an individual student's behavioural pattern (micro-level view). To answer *How usable is the* *designed elements (model / representation / tool)?*, I approached 4 co-researchers from our group. One of them was involved in the TPS study and rest 3 intended to use the method of analysis in their own upcoming studies. I gave them the TPS study data and the generated transition diagram and gathered feedback regarding the ease of understanding and limitations of methods developed in genesis stage.

5.6.2 Inferences drawn from tracing engagement pattern

The meso-level view assisted to build a model of engagement during the TPS activity. This descriptive model helped us to analyse proportions of the cohorts in each state of engagement in a phase of activity and further traced the transition ratio to the next phase. The calculated proportions of each state and the transition ratio was used to answer two research questions specific to this context of study; *How much student engagement occurs during the TPS activity?* and *How does the amount of engagement change as activity progresses?*

Additionally, the diagram helped to indicate patterns such as which is the most probable path of transition of engagement across phases and which stratum does most of the group members migrate to, etc.

If the researcher takes only a Macro-level view and tries to analyze the whole class, then the temporal transitions present in the data is lost in the aggregate. Similarly, a Micro-level view of individual student, makes it difficult to conclude about any existing patterns.

5.6.3 Findings regarding usability issues of State Transition diagram

The 3 researchers who tried to apply the model of analysis on the TPS data, indicated that the methods to compute the transitions were cumbersome and it required supporting methods to pre-process the data. The representation also was visually cluttered when the numbers of states or phases were more. While the model of TPS engagement was represented with State Transition Diagram, it just conveyed only information regarding forward transitions and the transition ratio were always with respect to the previous state in each phase. Researchers indicated that transition information can be with respect to the total number of records or even as proportions to the succeeding state. For example, a backward transition information would help to indicate what proportion of students who are in disengaged in the Pair phase were previously engaged in Think phase. Though such information could be easily calculated, the State Transition Diagram currently didn't indicate that information. Our findings regarding the difficulties in the use of State Transition Diagram are summarized in Table 5.3.

Table 5-3 Summary of findings regarding difficulties of use of State Transition Diagram

Findings	Inference	Required action
Method of computing the transitions were difficult and limited to only forward transitions	The transformation of the data was done manually with case by case basis of defining the criteria. For user some degree of automation is needed in processing the data.	Set up a standard data processing workflow, part of which can be automated with the help of existing data processing tool like MS Excel. .
The representation was visually cluttered	The State Transition diagram had its circles and boxes filled with colours which made the visual elements very dense.	Redesign visualization to reduce visual clutter

5.7 Discussion

Tracing temporal transitions was an important aspect to analyse engagement in our context to evaluate TPS implementation in a large classroom. The state transition model provided constructs to analyse engagement based on defined states of engagement and computing transitions across phases of the activity. This notion of states could be extended to attributes whose values can be grouped according to predefined criteria. Further researchers during evaluating the designed information artifact perceived studying transitions can be extended beyond attributes in time and across any attributes and possibly interpreted based on the context of the data. While this model seemed useful, it still remained cumbersome to apply, specifically with respect to the computation involved to calculate transition ratios from individual records and then visually represent that information. To address our findings regarding of the issues of usability and expand the concept of meso-level view to analyse transitions across multiple attributes, we stepped into the next refinement stage.

Chapter 6

Design and Development Phase - Stage 2: Refinement

6.1 Refinement stage: goals and objectives

In the first stage of the design and development phase, a model of analyzing temporal transitions at the meso-level was conceptualised. In this stage the goals were to address the limitations of the previous stage and refine the meso-level analysis model and its visualisation.

For the refinement stage, I once again considered researchers dealing with educational datasets as our primary users. Our objective was to implement existing technology to assist users in generating the required meso-level information and representing it visually. Further, we wanted to expand the concept of tracing transitions beyond temporal analysis to further analyse transitions across any attributes.

6.2 Selected context: Student's perception in effectiveness study

The chosen a research scenario of the refinement stage focused on understanding transitions in students' attributes. We selected a study where student's perception data was used to evaluate an instructional framework. The LAMP (Large-scale Addressing of Muddy Points) framework was designed as a solution to elicit and address doubts (muddy points) of different learners in a large classroom scenario. The developments in this refinement stage was in the context of this effectiveness study of LAMP in a large enrolment (450 students) introductory computer science course (CS1). The meso-level view in this context would analyse cohorts of different perceptions in the large group of students. The data in consideration is the students' response to a perception survey having multiple items.

The LAMP framework describes three phases, collection phase, addressal phase and closure phase (see Fig 6.1). In the Collection phase the teacher and TAs collects student's muddy points (MP) over 4 modes (inside class, outside class, MP posts on Moodle, collection of MP chits). In the Addressal phase, depending on the mode of collection and type of MP, they take specific action to address the MP. In the Closure phase the instructor highlights important MPs to the whole class. Interested readers can further find implementation details in Majumdar & Iyer (2013).

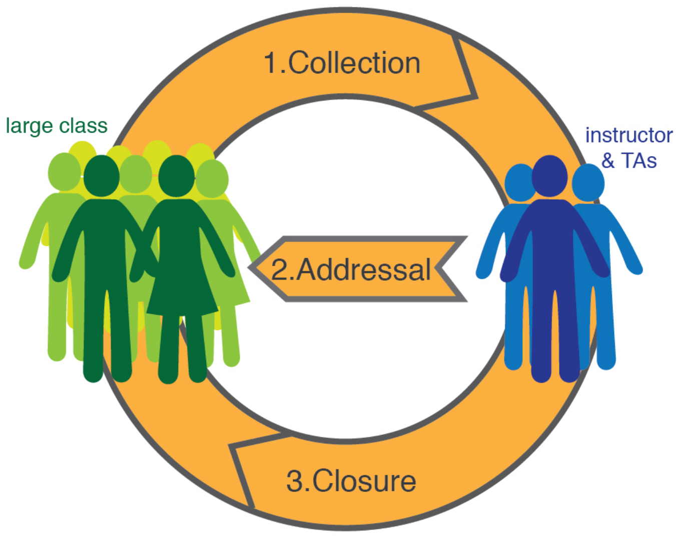


Figure 6-1 Phases of LAMP

Research objective of that specific study

To evaluate effectiveness of LAMP framework, was investigated *How effective is the LAMP framework?* from the perspective of the two phases of the framework.

- o How effective was it for *collection* of muddy point from the students?
- o How effective was it to *address* the muddy points of the students?

Dataset

To answer the RQ, we administered an online survey to the students with the following three questions items:

Answer the first two question on a 5-point Likert scale (1- strongly disagree, 5- strongly agree)

1. I had enough opportunities to put forward my queries to the instructor.

2. I got answers to my queries either in class or through Moodle.

3. Rank the following modes of asking queries:

   i. Raising question in the class

   ii. Putting a Muddy Point chit

   iii. Posting a Muddy Point discussion thread on Moodle

   iv. End of class discussion with instructor.

First two asked regarding their perception of effectiveness, of the collection phase and addressal phase respectively. Students responded to a 5 points Likert scale from strongly agree to strongly disagree. The third item was a rank order question on their preference of mode for muddy points collection.

Out of the 450 first year students registered in the course 340 responses were received. There were 274 completed data points (80% of total number of response), i.e., responses which had uniquely given preferences of mode of queries and answered the Likert scale questions. This Likert's scale data was segregated in three groups Agree (combining rating 4 and 5), Neutral (rating 3), and Disagree (combining rating 1 and 2).

Analysis

One of the objectives to evaluate LAMP framework was to find the most effective mode of eliciting and answering students queries. This would assist instructors to allocate further resources in the preferred and effective mode. Computing an overall preferred mode would include preferences of different groups of students based on their perception of effectiveness. For example, one group might perceive the framework as totally ineffective or another groups only credits partially effectiveness either for collection or for addressing respectively. To avoid that, first we found the proportion of the students who perceived they had enough opportunities to post MPs and further agreed that they had answer to their queries. Then we looked for the preferred mode of posting MPs of this specific cohort.

6.3 Refinement of Meso-level analysis

6.3.1 Approach to refine information artifact

To assist users to generate the meso-level information, I introduced steps to use pivot table functionality in MS Excel application and compute the required values of the proportions and transitions.

To avoid the visual clutter of the first iteration, I followed the data-ink ratio principle (Tufte, 1983) and made outlined templates for all possible diagrams that can convey up to 3 phases and 4 categories in each phase.

6.3.2 Refined constructs and visualization of the meso-level

After refinement the representation of the meso-level information was named as the Stratified Attribute Tracking (SAT) Diagram. The SAT diagram of the students' perception dataset is presented in Figure 6.2. A set of vertically aligned circle indicates a Phase, in the current scenario, a specific item in the perception survey. For example, the left stack of circles represents the Likert scale response to "(I) Had enough opportunities to ask question". Circles in the vertical stack represent Strata, here they are response categories, 'Agree', 'Neutral', 'Disagree'. The text in the circle conveys that the corresponding stratum has 185 observations, which is 68% of the total observations in that phase of response. The links represent the Transitions across strata of two different phases. The box on the path of each link conveys the Transition ratio to the corresponding linking strata. In Fig. 7, it shows 73% (forward transition ratio) of the 185 records in Agree stratum transit to the same stratum in the next phase.

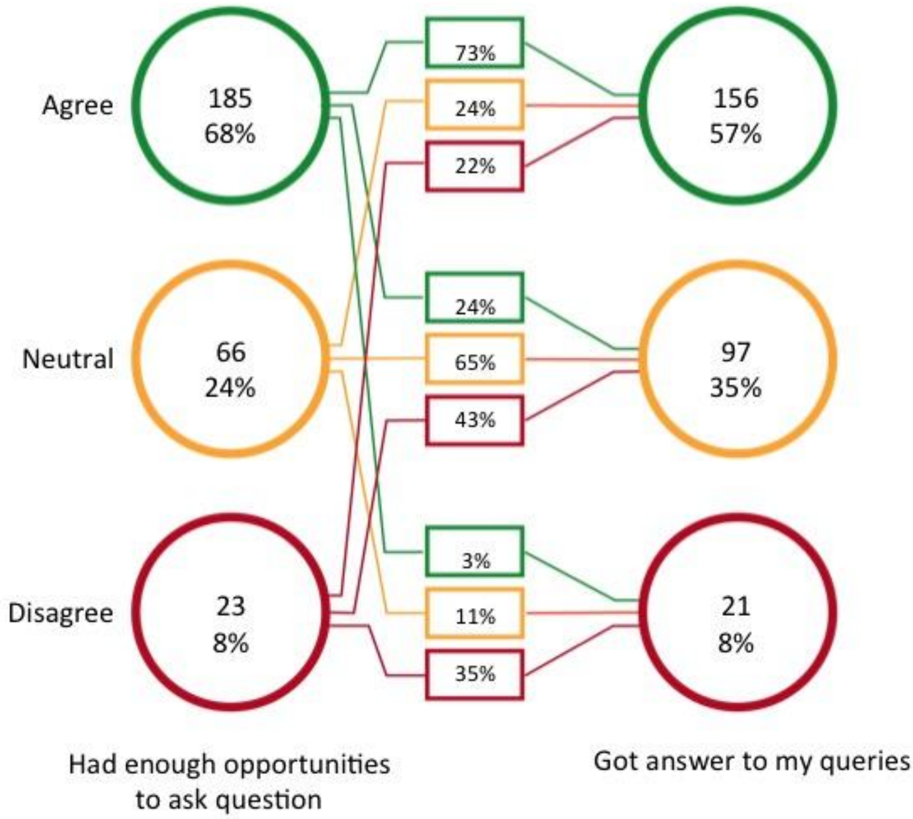


Figure 6-2 Stratified Attribute Tracking Diagram of students' perception (Majumdar & Iyer, 2014)

The definitions of the constructs at the end of refinement stage and modifications (if any) in this stage are given in Table 6.1.

Table 6-1 Constructs at the end of refinement stage

Constructs	**What does it define**	**Example**	**Modification**
Phase	Any attribute that is collected can be represented as a phase	Each perception question response can be represented as a phase	The definition is extended to any attributes that are collected independently or across time.
Strata	The specific groups defined by criteria set on attribute values defines strata	With perception of successful question response as attribute, 'Agree', 'Neutral', 'Disagree' are strata	In the previous cycle, only time instances were considered as the phase while their *states* conveyed groups at that time instance. States are modified to *Strata* that defines groups based on criteria set on any type of attribute and not limited to having a notion time. It can be considered only as a nomenclature change to include all types of attributes.
Transitions	The migration of cohort from one strata to another is represented as transition	Across different perception question, transition can represent the proportion of the Agree who moved to Disagree	Remained same
Transition ratio (TR) - Forward, Backward, Overall	TR for a particular transition is the ratio of the number of records which migrate in that particular transition to the number of records in the state from which (forward TR) or to which (backward TR) it migrates. The ratio with respect to the sample size is the overall TR.	If 20 students Agreed to the perception question 1 and 5 of them migrates to Neutral in Question 2, which had total 10 students, then the forward TR for Agree - Neutral is 0.25 (25%) and backward TR for Neutral - Agree is 0.5 (50%). The overall TR considering 100 students is .05 (5%)	The notion of forward, backward and overall TR is introduced.

6.3.3 Refined methods for meso-level analysis

In this stage I refined the 4-step meso-level analysis method developed in the previous genesis stage (see Figure 6.3).

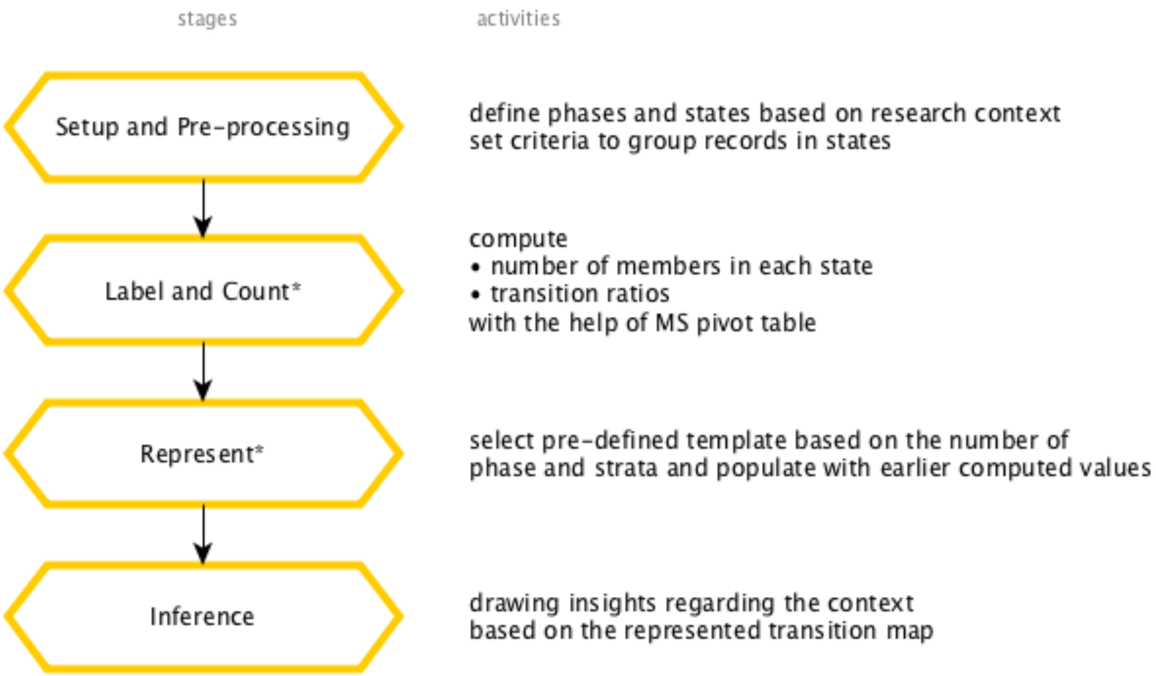


Figure 6-3 The refined* method in Refinement stage

I partially automated the Label and Count step by using pivot table functionalities in MS Excel. But users can potentially use any spreadsheet application. In the Represent step, we created predefined templates based on the number of phases and states for representing the information (see example of a 3x3 template in Fig 6.2). The users can select the corresponding template based on the number of strata and phases their context had and fill in the computed values of proportions and transitions in those templates for representation and analysis.

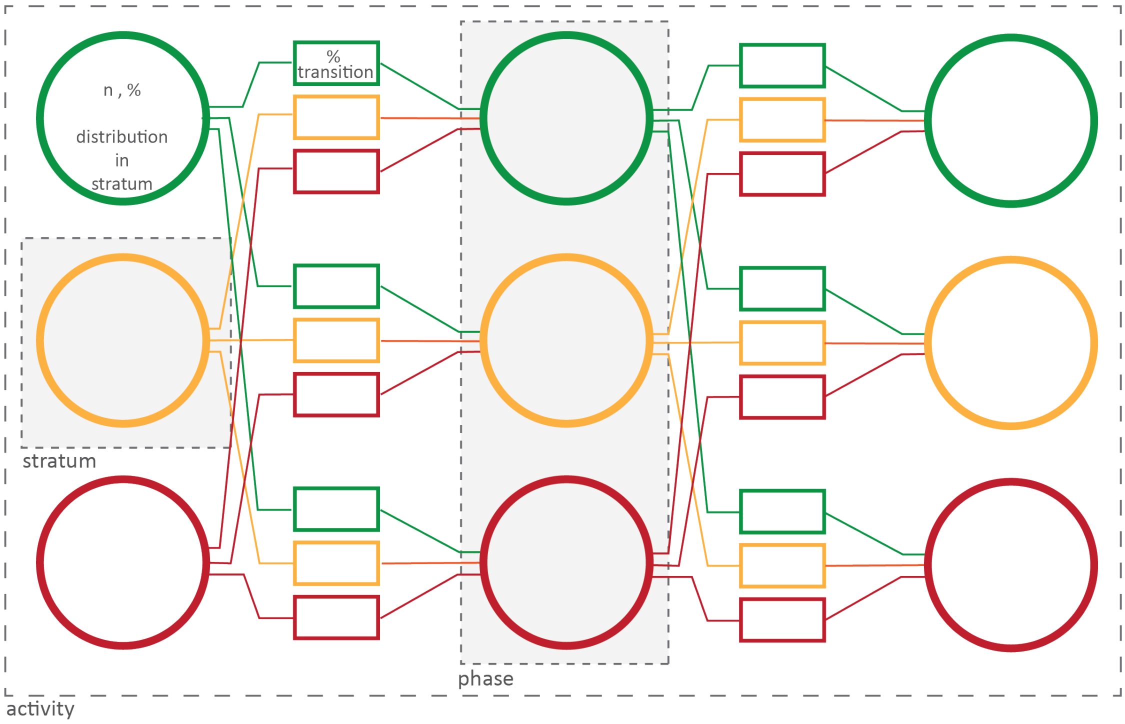


Figure 6-4 Template developed for representation in Refinement stage

6.3.4 Model of meso-level analysis

The descriptive model of meso-level analysis at the end of refinement stage is presented in Figure 6.5. It added that insights from meso-level view can be based on the transitions across multiple attributes and it has utility in terms of assistance in decision making.

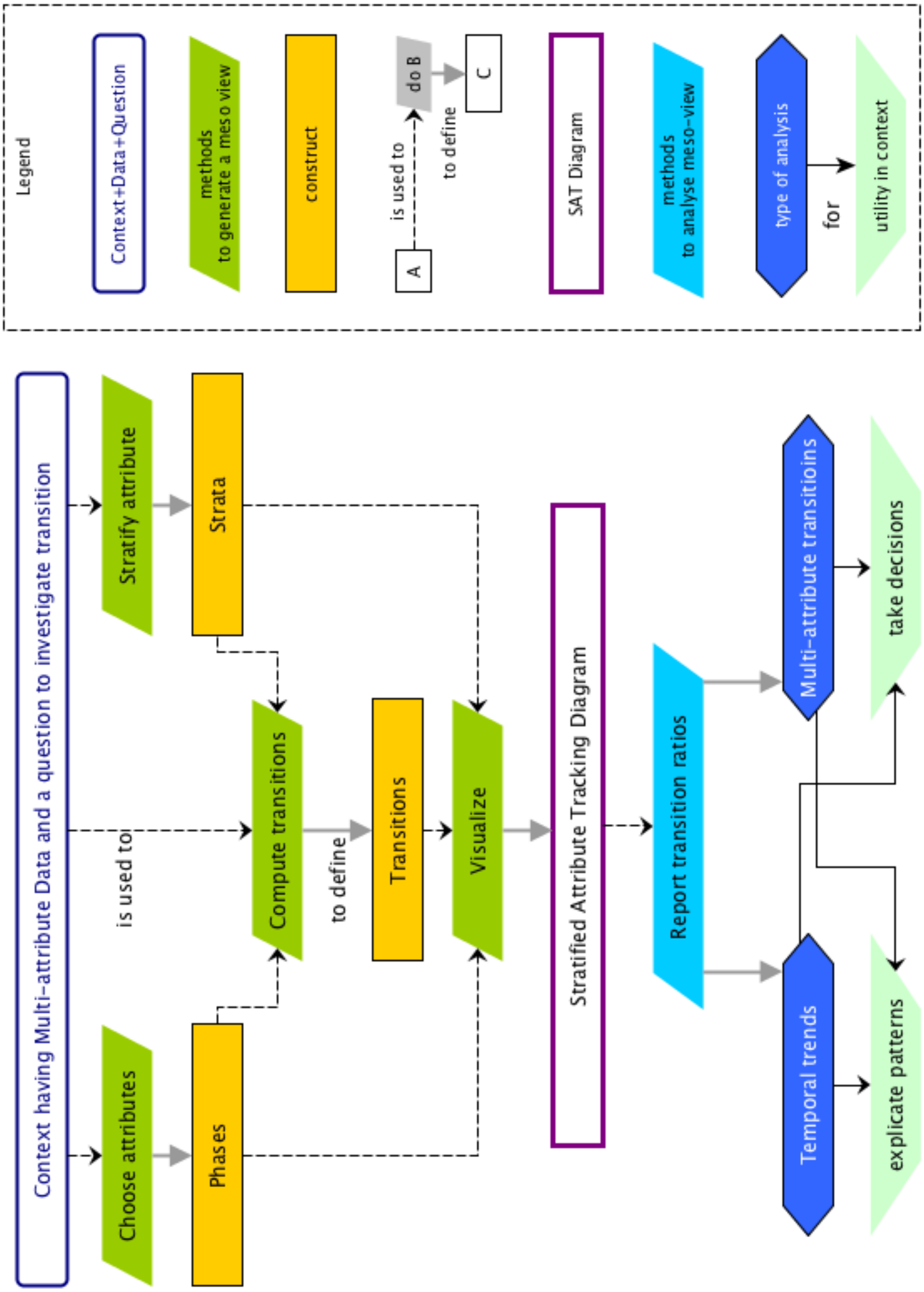
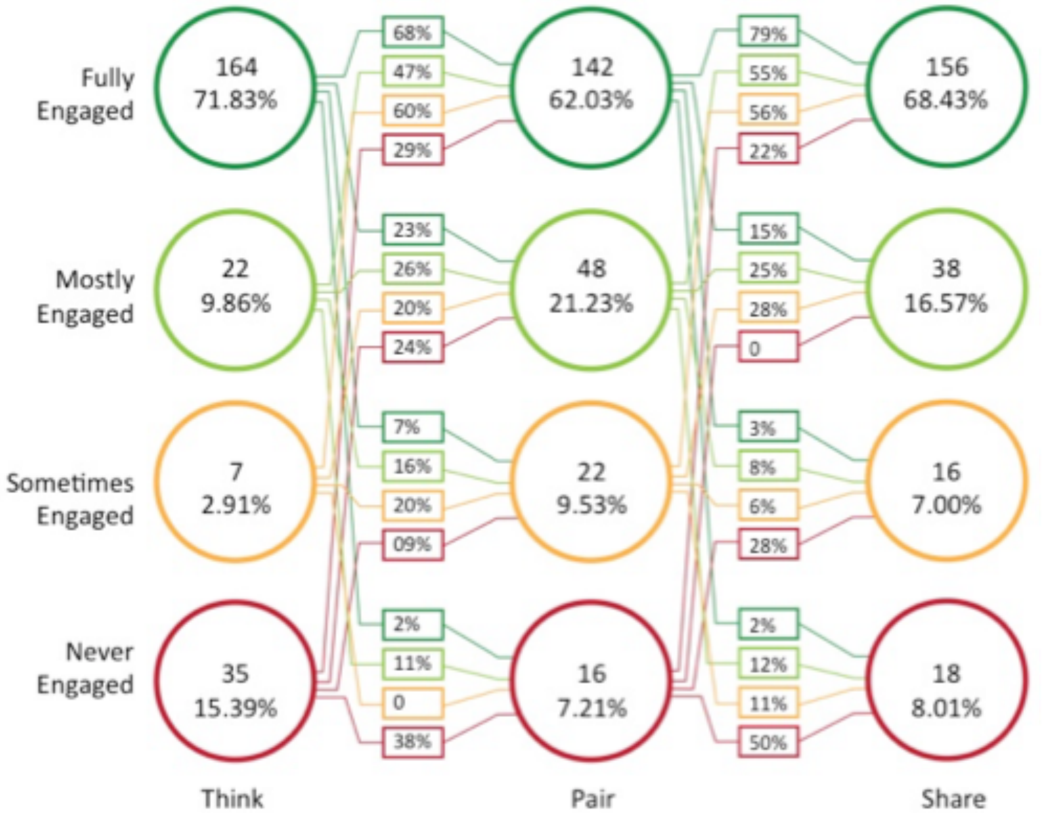


Figure 6-5 Descriptive model of the constructs and methods developed (Refinement Stage)

6.4 Refined concept and workflow of meso-level analysis

The model, constructs, methods and visualization of the artifact generated in the genesis cycle is summarized in the Table 6.2.

Table 6-2 Refined Meso-level information artefact at the end of Refinement stage

Model	Refined model to trace transitions across time and **attributes**.
Construct	State >**Strata**, Phase, Transitions, Transition ratios
Method	Semi-automated the method to generate meso-level view by using pivot tables in MS excel.
Representation	**Stratified Attribute Tracking Diagram** 

The analysis workflow is presented in Fig 6.6.

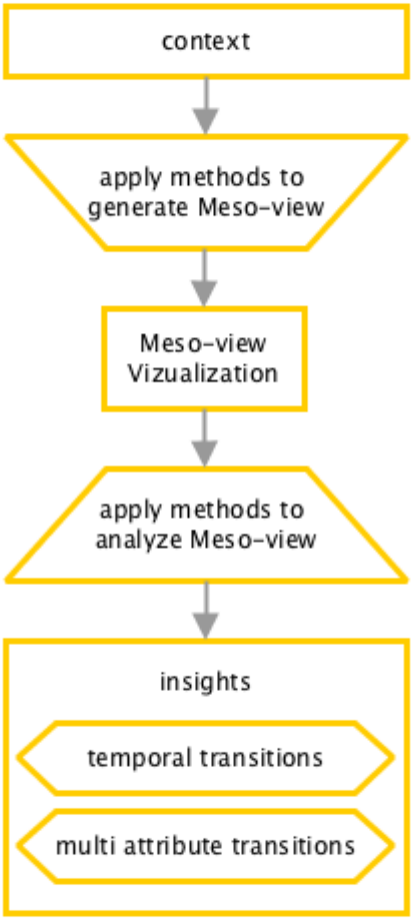


Figure 6-6 The Meso-level analysis workflow (Refinement stage)

6.5 Evaluation and findings of the refinement stage

6.5.1 Methods

In order to evaluate the model and SAT diagram in the refinement phase, I reflected on our own process of applying the model to trace transitions in the students perception dataset. Like in the genesis stage, I first analysed what inferences were drawn after applying the methods of stratified attribute tracking and then contrasted it with macro and micro level analyses in that context. Then, I approached 4 researchers from our group for feedback. They were the same participants of usability evaluation during the genesis stage and now were applying the method of meso-level analysis in their own context. Based on that experience they answered a 2-part survey. The first part was to describe the structure of their analysis based on the state transition diagram and the second part to highlight the benefits or drawbacks of its current methods.

6.5.2 Inferences drawn from student's perception survey patterns

A Macro view of the dataset would look at a class wide aggregate of the separate perceptions of whether learners could pose queries and then get their response. The Micro view would investigate a specific student's impression. These queries help to assess the overall effectiveness of the implementation (macro-view) or to identify specific preference of any particular learner (micro-view). We had gathered ranked choices of medium of asking muddy points and getting their replies via four different modes. We then wanted to find the most preferred mode of the class. This was not possible to indicate aggregate choice with individual learners indicating ranked preferences. The concept of looking at group of learners based on their joint perception with respect to posing and getting answer to the question seemed to highlight some preference of mode of posing the muddy points.

6.5.3 Findings regarding usability of Stratified Attribute Tracking diagram

The researchers who used the diagram highlighted its usefulness to report descriptive statistics of individual attributes as well as visualize transitions as captured in contingency table. One important criticism is quoted verbatim: "It (SAT Diagram) contained lot of information. This is great, but had to focus-in, and fade-out information which are irrelevant and relevant, respectively, for my presentation". Researchers confirmed the visual clutter was reduced with the new visual form. The finding and their inferences are tabulated below

Table 6-3 Summary of finding regarding the difficulties of use of State Transition Diagram

Findings	Inference	Required action
The methods to compute transition patterns across multiple phase were difficult	The pivot table method to compute transitions was limited to two phase	Separate implementation of computing transition values were required
There can be further visual mapping of representation to the data visualised.	There was scope of mapping visual elements to the constructs of the information and the tasks that the users intend to do with the information	Redesign the visualization to express visual idioms which assist to convey the notion of cohorts required during meso-level analysis. Find appropriate visual elements to encode the data variables

6.6 Discussion

The refined meso-level analysis model in this stage was called Stratified Attribute Tracking. At the end of the first stages we had a proof of concept that tracing transition patterns is a valid analysis technique which highlights patterns at the meso-level. In the second stage we expanded the concept of tracking transitions from temporal attributes to multi-attribute scenario. In our specific selected research scenario, we analysed transitions between items of perception survey. Considering the implemented LAMP framework, the analysis helped to measure proportion of specific cohort which agreed on both the survey items. The proportion of that transition indicated both effectiveness of the framework and assisted to select preference order of mode of clarifying muddy points as recommendation.

The pivot table calculations assisted the user to compute the proportion in each phase and transition ratios across them from their original record. Modifying the visual form with the outline and grid structure improved the readability of the diagram with respect to the previous version. It was in accordance to the data-ink ratio principle (Tufte E., 1983). During the feedback sessions with fellow researchers they also highlighted that most of their findings in terms of collections of similar transitions and not individual transitions. For instance, cohorts which remained in the same strata across phases. These notion of transition collectives or patterns also required further elaboration as a construct.

While the methods involved at the end of the refinement phase used basic technology to process the data and represent the information, the formative feedback indicated scope of implementing a software tool to assist user to fully process their data and interact with their dataset to find the patterns. This led us to the third stage of implementation of a tool based on the stratified attribute tracking model.

Chapter 7

Design and Development Phase - Stage 3: Implementation

After the initial stages of conceptualisation and refinement of a model to analyse temporal and multi-attribute transitions at the meso-level, in stage 3 we implement a tool based on that developed model. This tool would assist the users to analyse transition with a generated visualization from their dataset.

7.1 Implementation stage: goals and objectives

In this stage I explore the applicability of the concept of Stratified Attribute Tracking with instructors as primary user. I want to study what assistance can a meso-level analysis provide to an instructor for taking instructional decisions during an active learning session. The objectives for implementation stage were:

- Select a context that involves an active learning strategy where analysing transitions can help the instructor take instructional decisions.
- Design an interactive visualization of the transition information at a meso-level.
- Create a tool to enable users visualise their data and analyse the meso-level view.

7.2 Context of Active Learning: Peer Instruction

Peer Instruction (PI) (Mazur, 1997) is an instructional strategy to facilitate active learning. In PI (see Fig 7.1 for activity flow), students are engaged in active learning by participating in a deep conceptual multiple-choice question (Q1) on any topic. In the first round, they vote individually (response to Q1). This is followed by a discussion with the neighbour to justify their answer. Then they re-vote their choice on the basis of the discussion (response to Q1ad) to the same question again. 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 7-1 Activity flow in a classic Peer Instruction (PI) activity

Smith et.al (2009) further extended the classic versions of PI for an undergraduate genetics course and added an Isomorphic question (Q2) as a third phase of voting (see Fig 7.2). An isomorphic question is on the similar concept as Q1 but has minor variations. Later, Porter et.al (2011) investigated the effectiveness of PI with isomorphic questions in the domain of Computer Science (CS) education.

Figure 7-2 Modified PI activity flow with an isomorphic question (Q2)

Clickers or similar personal response systems are often used technology support to collect student responses. Instructors may choose to show the variation in distribution of answer choices after first round voting, second round re-voting (stage 2 and stage 5 in Figs. 7.1 and 7.2) and after voting in isomorphic question (stage 7 in Fig. 7.2), in the form of a Histogram. Success of the activity is gauged based on shift towards correct option by majority of the class. Readers interested in implementing Peer Instruction as an evidence-based instructional practice in different disciplines like Physics, Chemistry, Biology and Computer Science can look at the review by Vickrey et.al. (2015).

Analysis objective of that specific scenario

The objective is to trace transitions of students' response during the various phases of the PI activity.

Dataset

We reconstructed random student responses across three PI phases such that it matched aggregate results of Porter et.al (2011). While reconstructing 300 clicker responses as answers to 3 multiple choice questions by 100 students, we assumed 4 options with option 1 as the correct answer for each of the three questions. The incorrect options in each question is linked to an alternate conception in the assumed topic. An example of our generated data is: student #46, response to {Q1, Q1ad, and 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. Figure 7.3 presents the histogram of the voted options that match the study's overall accuracy values across the different voting phases.

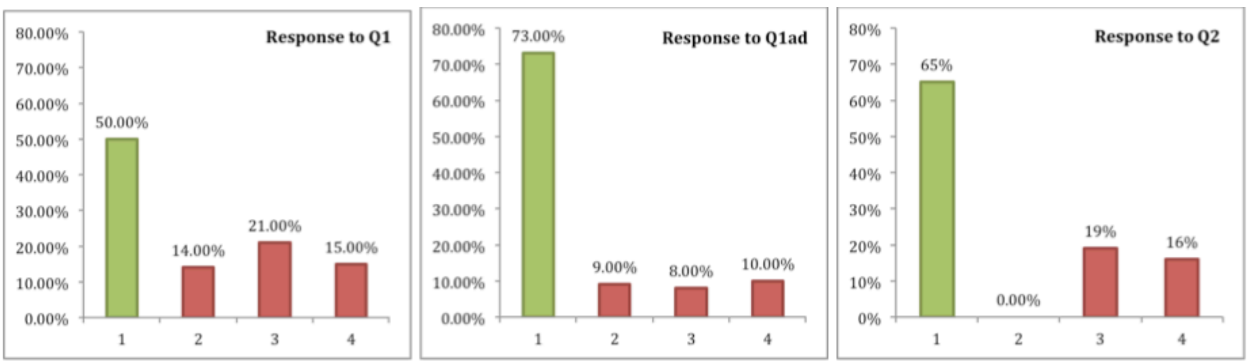


Figure 7-3 Histogram of different response

Analysis

Researchers initially were interested to analyze only aggregate level learning gain during such activities (Hake, 1998). Later others (Smith et.al 2009, Porter et.al 2011) analyzed transitions of accuracy across attempts by using Flow Charts. It is to be noted that the transitions among alternate conceptions, as reflected by responses across the two attempts, are not highlighted. It is interesting to observe those transitions (Wittman et.al, 2014) as they help to decide post discussion activities (Majumdar, 2015a). To the best of our knowledge there are no tools available that can assist instructors in tracking the transitions of responses and analyzing patterns in real time.

7.3 Implementing meso-level analysis with web-based tool

7.3.1 Approach and technology to implement meso-level analysis model

I first represented the information derived from the Stratified Attribute Tracking as an interactive visualization, iSAT diagram. To design this interactive visualization, we developed its visual and interaction idiom (Munzner, 2009). We then implemented a web-based tool to process the raw data to create this interactive visualization. Further the tool aimed to enable users interactively analyse transition patterns that exists in their visualised dataset. We used the D3JS library (Bostock,2011) for plotting the data and interacting with it. Independent JS functions handled data transformations. With the interactive visualization and affordances of a web-based tool, we evolved specific analysis tasks that would give insights to the users.

I studied how the perspective of meso-level transitions inform us in the context of Peer Instruction activity and evolved the components of the SAT model.

7.3.2 Evolution of constructs and visualization of the meso-level view

Figure 7.4 shows the iSAT visualization for the regenerated data set of students response to multiple choice conceptual question. iSAT has two modes, the Overview mode and the Exploration mode. The Overview mode (see Fig 7.4) provides the static distributions of each stratum and transitions in between them. The user enters the Exploration mode once they interact with the visualization through click/tap to explore further details of any cohort represented (see Fig 7.5).

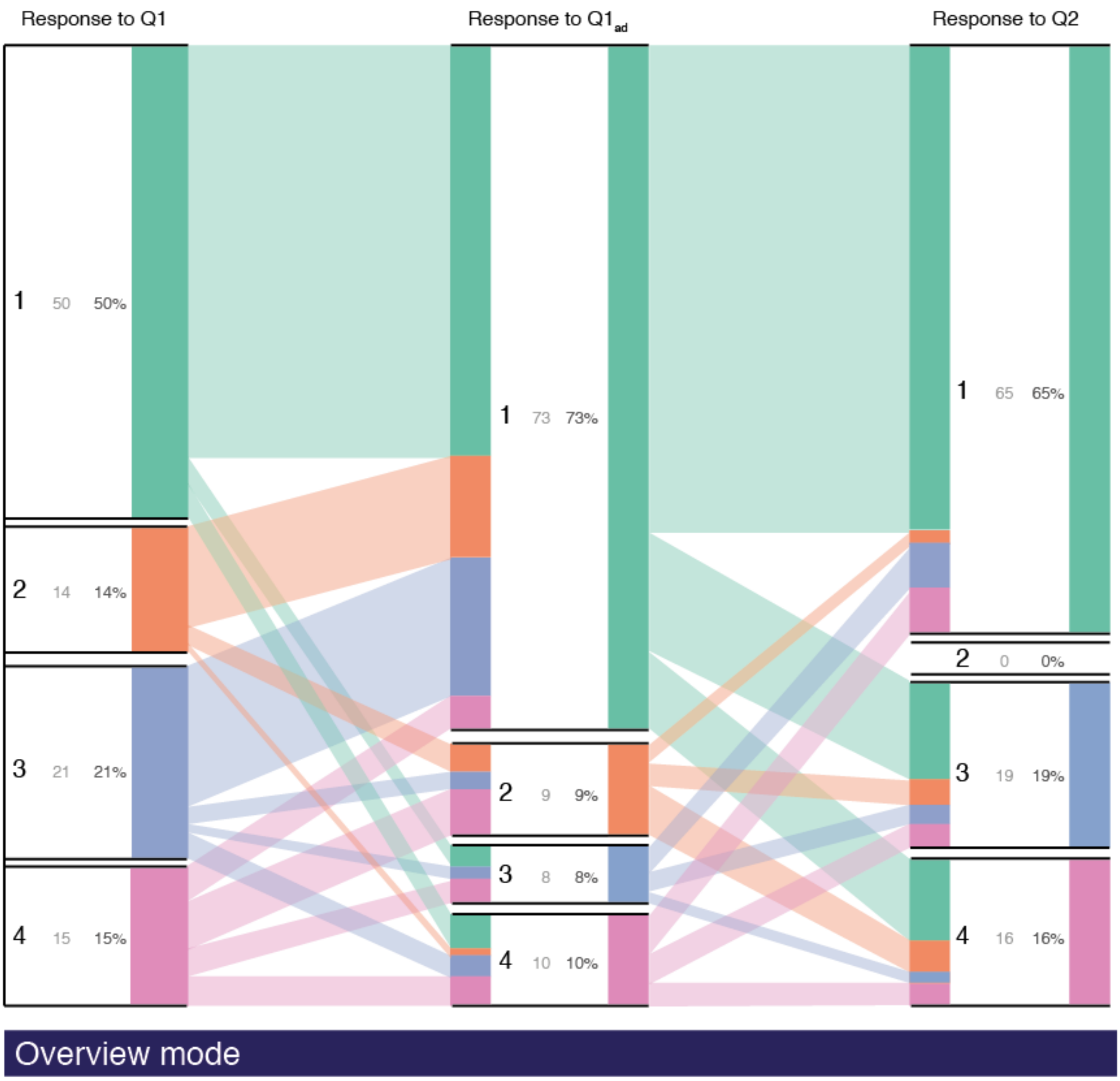


Figure 7-4 Interactive Stratified Attribute Tracking Visualization: overview mode

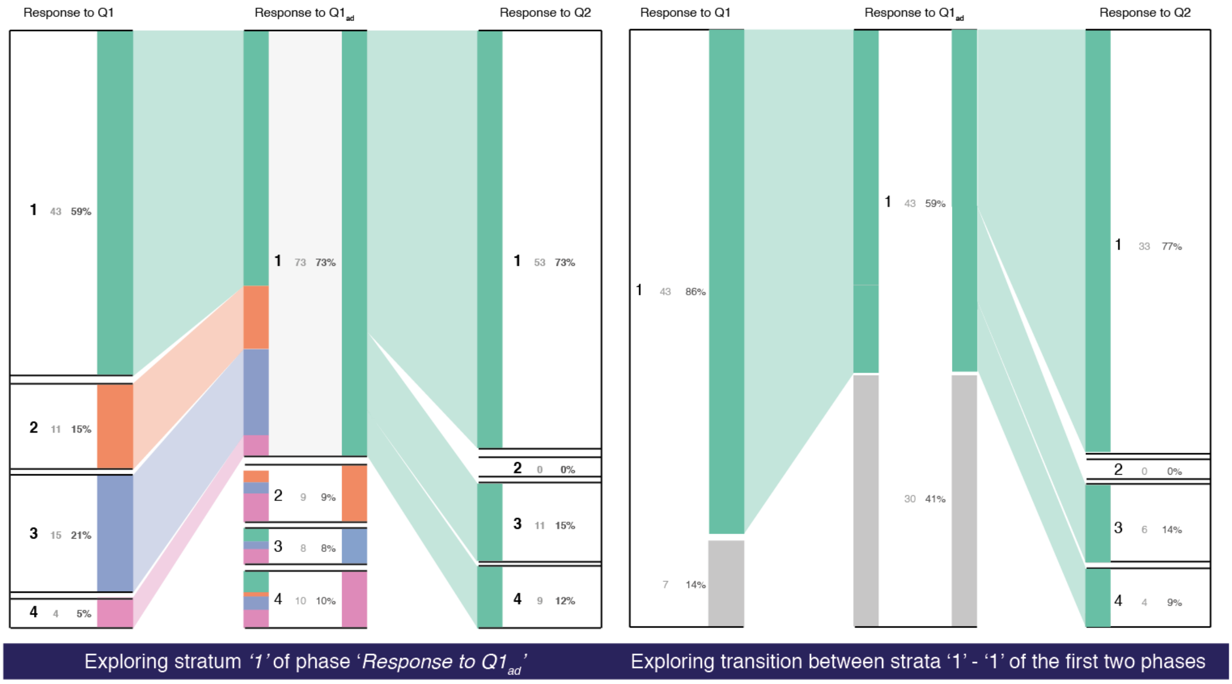


Figure 7-5 iSAT Visualization: exploration mode

I answered the design question *How can the meso-level view be represented visually?* by mapping principles of visual design and interaction design to the create the artifact. Table 7.1 highlights the mapping of the principles to the iSAT visualization.

Table 7-1 Applied visual and interaction design principles to iSAT

Gestalt Principles (Chang, D., Dooley, L., & Tuovinen, J. E., 2002).	
1. Balance/symmetry	iSAT maintains a symmetry regarding the input and output ratio bars.
2. Continuity	left to right flow is maintained by the linking bands and further emphasized by the colour
3. Closure	the dividing line gives closure in each stratum. strata whose elements are absent, the gap is maintained to give closure
4. Figure-ground	-
5. Focus	the highlighted value is made bold
6. Isomorphic correspondence	each column has two walls indicating the input and output ratio.
7. Good form	-
8. Proximity	the labels are in the mid position of each stratum
9. Similarity	-
10. Simplicity	the cohort of interest is only highlighted
11. Unity/harmony	the dividing lines help to maintain the visual unity of the stratum

Grouping principles, (Bae, J., & Watson, B., 2014)	
1. proximity	each stratum belonging to a particular phase is grouped and aligned vertically, the input ratio is denoted by the group on left and distribution in a phase on the right
2. similar shape	each phase is depicted by the column structure
3. similar colour	each strata is denoted by a colour and the transition is represented consistent with that colour
4. similar size	100 % is always denoted by the denoted by the same height in the diagram
Static and Interactive aspects in visualisation (Munzner T., 2014)	
Static Aspects of visualisation	
1. Weber's law: we judge based on relative not absolute differences	iSAT has aligned and banded stratum for comparison of the distribution in each phase
2. Marks	rectangular areas representing stratum - rectangular area representing phase - areas representing transitions
3. Channels	
3.1 position	each col corresponding to the strata in one phase are vertically aligned, they are sorted and stacked from top to bottom (higher / desirable state on the top)
3.2 colour	each col on the right corresponds to a stratum and has a distinguishable colour
3.3 tilt	Not considered
3.4 size	each col size is proportional to the contribution of the stratum in that phase. The logic is nested for the left col representing input ratios
4. Effectiveness	
4.1 Accuracy	according to Steven's law length has the perception matching true value - hence used to distinguish stratum proportion
4.2 Separability	position and colour - colour taken from Brewer, Cynthia A., 200x. http://www.ColorBrewer.org
4.3 Pop-out	Not considered - but rest of the data is removed to highlight cohort of interest
Interactive aspects of visualisation	
5. Changing	
5.1 selection	the text label is bold
5.2 highlighting	Not considered
5.3 navigating	Not considered

5.4 sorting	Not considered
5.5 changing visual encoding	Not considered
6. Latency	Not considered

Phases, Strata, Transitions and Transition ratios remain same as was developed in the previous cycles. An additional concept of pattern of transitions emerged in this cycle. The pattern would qualitatively group certain transitions together. For example, the group of all the transitions in which records have the same strata gives an Aligned pattern. In our specific context of analysing PI data, in each phase (each voting phase of PI), there were same number of strata (number of alternative voting options for the students). For four options and three phases it resulted in 64 possible transitions. We introduced total 7 named patterns to group these transitions (see Appendix II). We could adapt most of these concepts of patterns in the PI context from the works of Wittman et.al. (2014).

Table 7-2 Constructs developed in Implementation stage

Constructs	What does it define	Example in the context of PI	modification
Phase	Any attribute that is collected can be represented as a phase	Each perception question response can be represented as a phase	Remained same.
Strata	The specific groups defined by criteria set on attribute values defines strata	With perception of successful question response as attribute, 'Agree', 'Neutral', 'Disagree' are strata	Remained same.
Transitions	The migration of cohort from one strata to another is represented as transition	Across different perception question, transition can represent the proportion of the Agree who moved to Disagree	Remained same.
Transition ratio (TR) - Forward, Backward, Overall	TR for a particular transition is the ratio of the number of records which migrate in that particular transition to the number of records in the state from which (forward TR) or to which (backward TR) it migrates. The ratio with respect to the sample size is the overall TR.	If 20 students Agreed to the perception question 1 and 5 of them migrates to Neutral in Question 2, which had total 10 students, then the forward TR for Agree - Neutral is 0.25 (25%) and backward TR for Neutral - Agree is 0.5 (50%). The overall TR considering 100 students is .05 (5%)	Remained same.
Patterns	A set of Transitions which can be grouped together can be indicated as a pattern	The group of all the transitions in which records have the same strata gives an Aligned pattern.	Qualitative grouping of the transitions.

7.3.3 Implemented methods for meso-level analysis

The implementation of iSAT tool to generate the meso view from the data follows the methods developed in genesis phase (Figure 5.6). The tool would compute all the proportions and determine the parameter values to create the visualization by processing a CSV file which is provided by the user. Then the user can execute a set of visual information retrieval tasks to gather relevant insights in their context. These tasks were designed as interaction affordances of the iSAT visualization and implemented in the web tool. Figure 7.6 provides the updated methods developed in this implementation stage. I give further details regarding determining constructs of analysis, specification of the CSV file of dataset, and visual analysis task in next chapter.

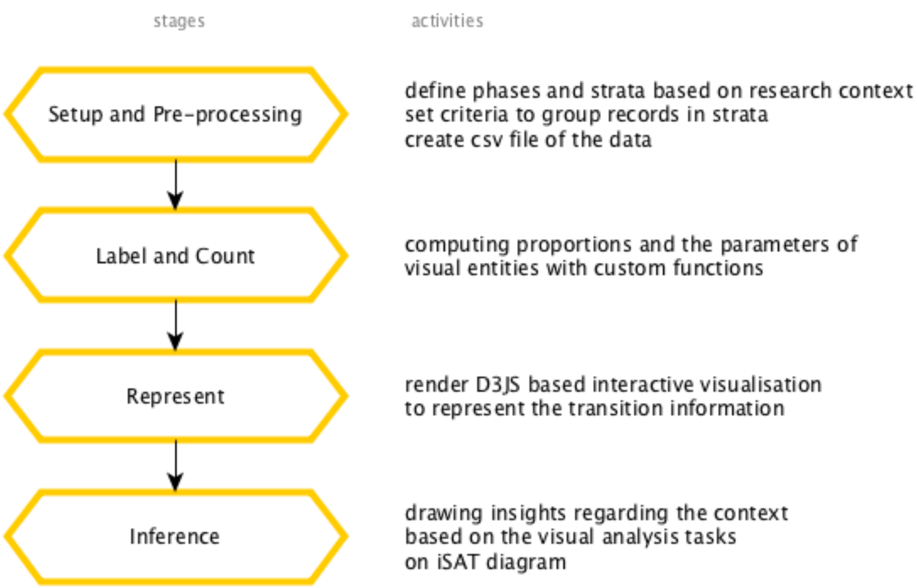


Figure 7-6 The methods in the Implementation stage

7.3.4 Model of meso-level analysis

The descriptive model of meso-level analytics with iSAT, in this implementation cycle, is presented in Figure7.7.

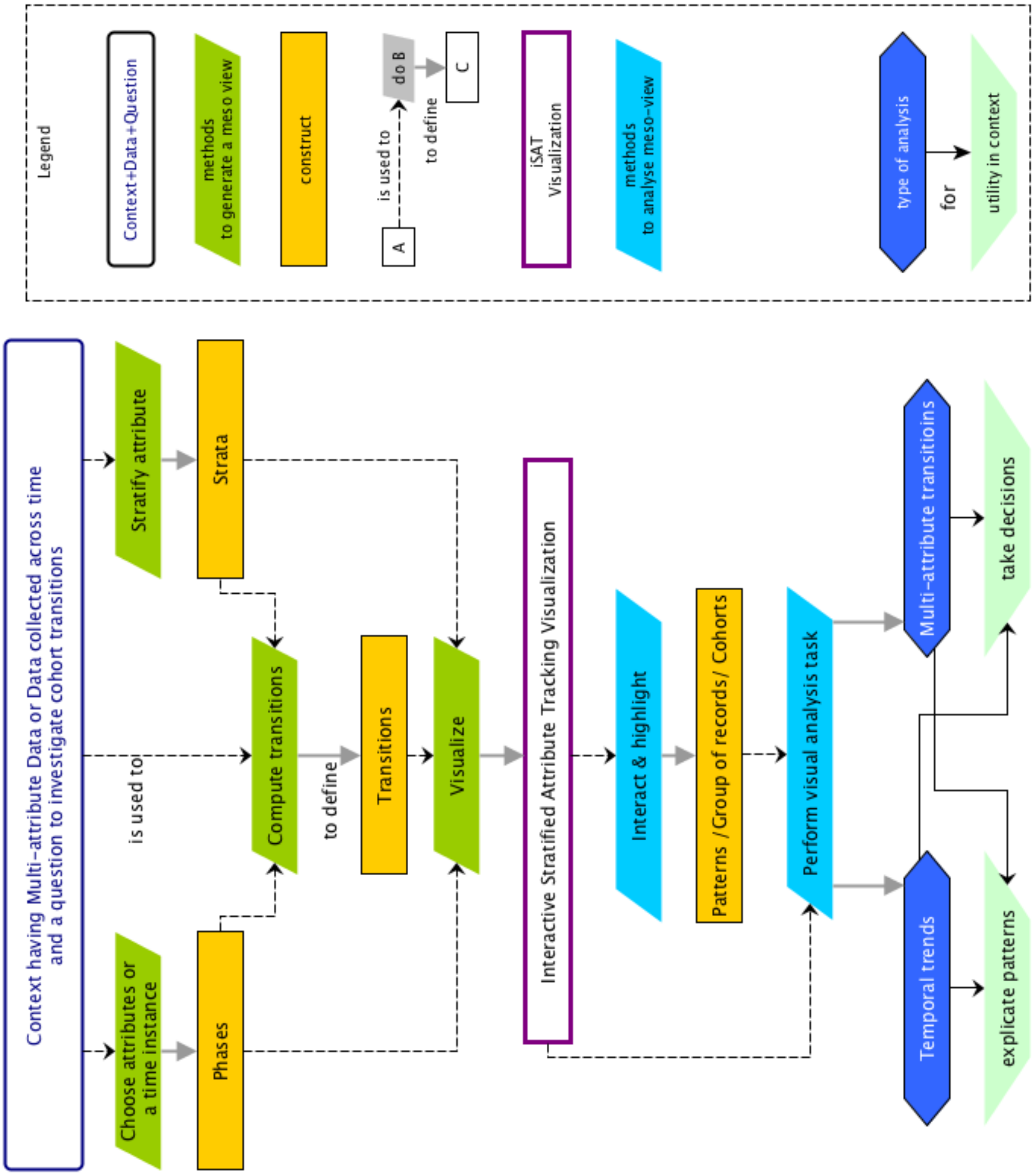


Figure 7-7 Descriptive model of the constructs and methods developed (Implement Stage)

7.4 Evaluation and findings of implementation stage

7.4.1 Methods

To analyse how tracking transition of students' response across the phases of the PI activity can inform instructional decision making in the context of Peer Instruction, I argue based on literature how the generated named transition patterns can assist the instructor for real time orchestration in their classroom. The output of this stage was introduced as the working solution and more formal user testing were done with new users in the next evaluation phase.

7.4.2 Inferences drawn from tracing response in conceptual test during PI

iSAT explicates the rich transition patterns in the three-phase isomorphic PI activity response. The structure of the visualization gives the instructor an overview of the patterns, and the interactive tool then allows them to explore further details about those transitions. We explored all the 64 possible transition patterns across three voting phases each having four options. Out of them, we defined seven categories of specific transition patterns, which can be interpreted by the instructor who is conducting the PI activity. Some of the patterns of interest were adopted from the consistency plot analysis done in the context of physics education research to analyze pre-post student responses (Wittmann and Black 2014). There is scope of instructional decision making based on analysing transition patterns in students' response.

7.5 Discussion

In this implementation cycle we develop a web based tool to support the meso-level analysis. A construct called Patterns was added which represents a set of transitions grouped by its nature. We also modified the visual idiom of the representation to further aligned to the nature of information that was being presented. A set of interactions were designed in the tool to aid visual analysis based on the different type of information retrieval task. The analysis workflow with the iSAT tool is presented in Fig 7.8.

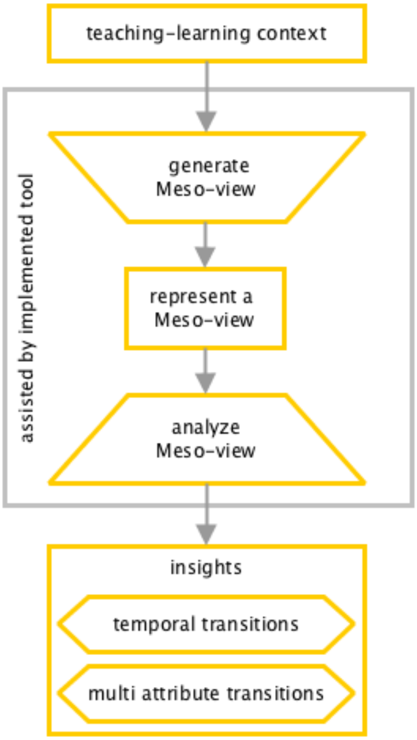


Figure 7-8 The Meso-level analysis workflow (Implement stage)

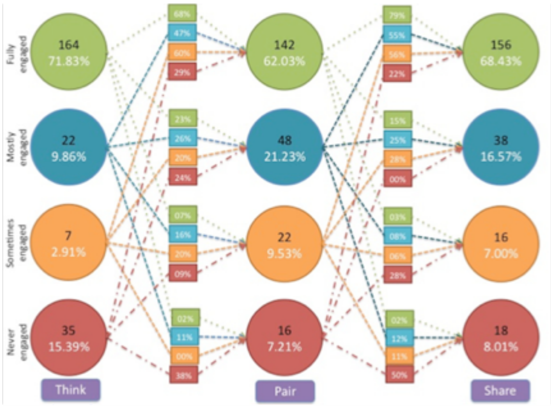
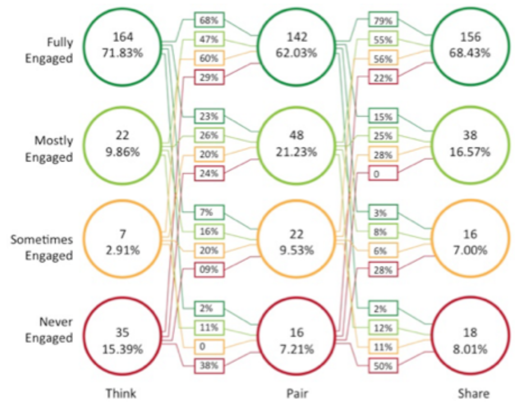
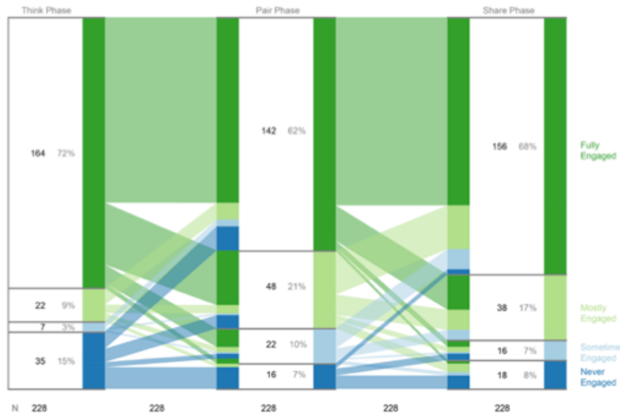
In our chosen context of studying student response pattern across the three phases of Peer Instruction, we could define specific instructional decisions that an instructor can take based on iSAT analysis (see Appendix II for details).

7.5.1 Summary of evolution of meso-level analysis

The evolution of the working-concept across the three stages of designing, refining and implementing is summarised in Table 7.3.

Before proceeding to the Evaluation Phase, we present the details of the developed solution in next chapter.

Table 7-3 Artefact at the end of implementation phase

	Genesis Phase	Refinement Phase	Implement Phase
Model	Created model to trace **transition across time.**	Refined model to trace transitions across time and **attributes**.	**Implemented model with the help of iSAT tool**
Construct	**State, Phase, Transitions, Transition ratios**	State >**Strata**, Phase, Transitions, Transition ratios	**Patterns**, Strata, Phase, Transitions, Transition ratios
Method	Developed a method to generate the meso-level information of a dataset.	Semi-automated the method to generate meso-level view by using pivot tables in MS excel.	The iSAT tool generated the meso-level view. Analysis of meso-level view was facilitated with information foraging tasks assisted by interactions with the iSAT tool.
Representation	**State Transition Diagram**	**Stratified Attribute Tracking Diagram**	**Interactive Stratified Attribute Tracking Diagram**
			

Chapter 8

Developed Solution: iSAT for meso-level analytics

Over the three stages of design and development phase I conceptualised a meso-level view of the dataset, and visually represented it to analyse transition patterns. Before discussing evaluation phase of our research, in this chapter I present the details of the created iSAT model and the operations of the developed tool.

I applied the paradigm of Design Science (Henver, et.al. 2004) and created an information artifact to assist meso-level analysis. We call it Interactive Stratified Attribute Tracking (iSAT) model. We developed a web-based tool to implement this model. The iSAT tool (www.et.iitb.ac.in/iSAT) helps users to visualise their dataset and interactively find transition patterns in their data.

For illustration we consider a Peer Instruction (PI) learning scenario, similar to the one described in Chapter 7. We describe the context of analysis of PI response data in section 8.1. The iSAT model of analysis for that scenario is described in section 8.2. The construct of iSAT and its corresponding visual representation is described in section 8.3. Then section 8.4 defines two sets of methods associated with the artifact, one for generating the information from raw data and other for interpreting that information with the help of the visualization. The web based iSAT tool is described in section 8.5. Figure 8.1 organises the concepts regarding iSAT and this chapter.

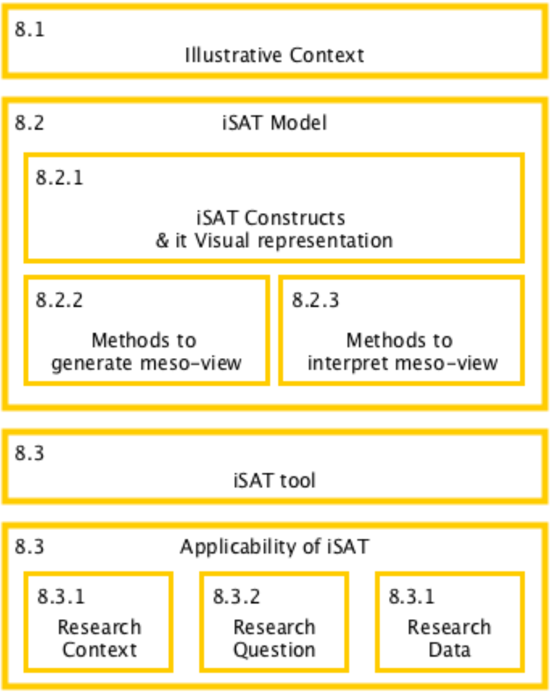


Figure 8-1 Our solution - iSAT model and the iSAT tool

8.1 Illustrative context: Analysis of Peer Instruction activity data

Let us consider the same context of Peer Instruction (PI) as described in Chapter 7. For the ease of explanation, let us consider response accuracy of each student for all the three questions attempt as our data for analysis. Table 8.1. gives a sample dataset

Table 8-1 A sample of dataset having accuracy data of students' response

Student #	Accuracy in Q1	Accuracy in Q1 after discussion	Accuracy in Q2
Student 1	Correct	Correct	Correct
Student 2	Incorrect	Correct	Incorrect
Student 3	Correct	Incorrect	Incorrect

8.1.1 The Micro-macro-meso-level of analysis

Accuracy data of each student convey whether they are correct or incorrect in their voting of options for each of the PI questions. A micro-view analysis would focus to answer questions regarding a single learner or a single question (highlighted in table by blue cell colour in Table 8.2).

Table 8-2 Micro-level analysis

Student #	Accuracy in Q1	Accuracy in Q1 after discussion	Accuracy in Q2
Student 1	Correct	Correct	Correct
Student 2	Incorrect	Correct	Incorrect
Student 3	Correct	Incorrect	Incorrect
...	:	:	:
Student n	Incorrect	Correct	Correct

A macro-view analysis would mean to aggregate the dataset at a class or activity level. One can analyse percentage accuracy of the class during each voting or average the accuracy for the whole class across the activity. The focus (highlighted in table by blue cell colour in Table 8.3) is to aggregate the parameter across different attributes and records.

Table 8-3 Macro-level analysis

Student #	Accuracy in Q1	Accuracy in Q1 after discussion	Accuracy in Q2
Student 1	Correct	Correct	Correct
Student 2	Incorrect	Correct	Incorrect
Student 3	Correct	Incorrect	Incorrect
...	:	:	:
Student n	Incorrect	Correct	Correct
Overall	50% correct	73% correct	65% correct
	Average 62.6% correct		

A meso-level perspective with iSAT model would analyse the transitions of membership of certain accuracy group across the different questions. In the tabular representation the transitions are indicated by the variation in the cell colours (green and brown in Table 8.4). iSAT diagram would further aggregate the transition and interactively help to find patterns.

Table 8-4 Meso-level analysis

Student #	Accuracy in Q1	Accuracy in Q1 after discussion	Accuracy in Q2
Student 1	Correct	Correct	Correct
Student 2	Incorrect	Correct	Incorrect
Student 3	Correct	Incorrect	Incorrect
Student 4	Incorrect	Incorrect	Incorrect
...	:	:	:
Student n	Incorrect	Correct	Correct

8.2 Model of iSAT

The iSAT model of analysis describes how to trace transition patterns in a dataset to analyse cohorts. The data can have same attributes collected across time (for example response accuracy across different voting period of PI activity) or different attributes (for example students' perception on different survey items). We consider multi-attribute data of learners where each attribute At_i , is collected at a given instance of time (t_j) or across instances t_js. Given any such dataset, the iSAT model prescribes three types of transition analysis; transitions across time, transitions across attributes or transitions across any of the combination of collected attributes over time. Figure 8.2 illustrates the transitions that can be studied when 2 attributes are collected across 2 temporal instances. An example context would be analyzing pre and post-tests of students on two different test items.

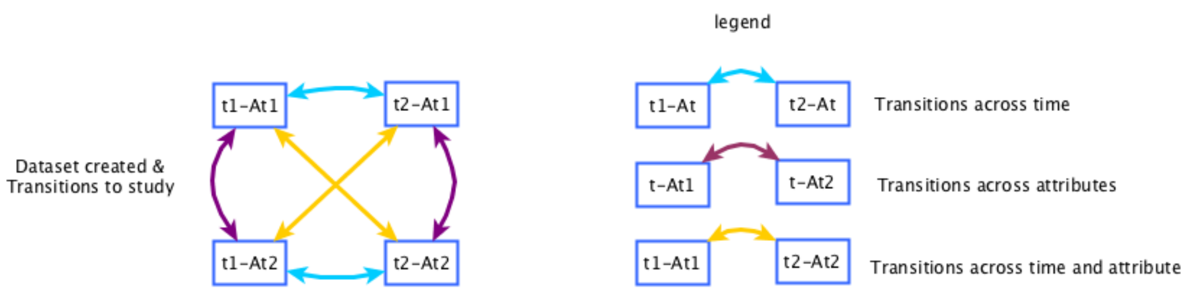


Figure 8-2 Possible transitions of multi attribute data collected across time

8.2.1 Visual representation of constructs of iSAT

The constructs define the vocabulary of the model of analysis (see Table 8.5). iSAT has *Phases, Strata* and *Transitions* as constructs. In our context of Peer Instruction, each voting instance can a Phase. The accuracy of the response defines the Strata and the Transition traces changes in the students' accuracy across phases. For creating a representation of the meso-level information, we chose the nested model for visualization design proposed by Munzner (2009). This model suits our objective to create an interactive visualization. The constructs are represented by a visual element (mark) whose properties (channel) link to the data value of the constructs. In iSAT, line is the chosen as the fundamental mark. Height of the line encodes proportion of each Stratum. For Transition it is encoded in the width of the band. Additionally, each Stratum has a unique colour and is stacked on one another in their corresponding Phase. Phase is represented as a glyph, (a collection of different marks, like lines and texts). Two bounding vertical lines forms a column that contains the information of Phase. The right set of main bars in it represents the strata corresponding to that phase. A line separates each stratum. The left set of sub bars in the Phase column corresponding to each stratum, represents the corresponding incoming proportion from the previous phase. A text label conveys the names of strata, the value of number of records and the percentage of total corresponding to each stratum. This iSAT visualization represents a meso-level view of the dataset in terms of the transitions of different cohorts that exists (see Fig 8.3).

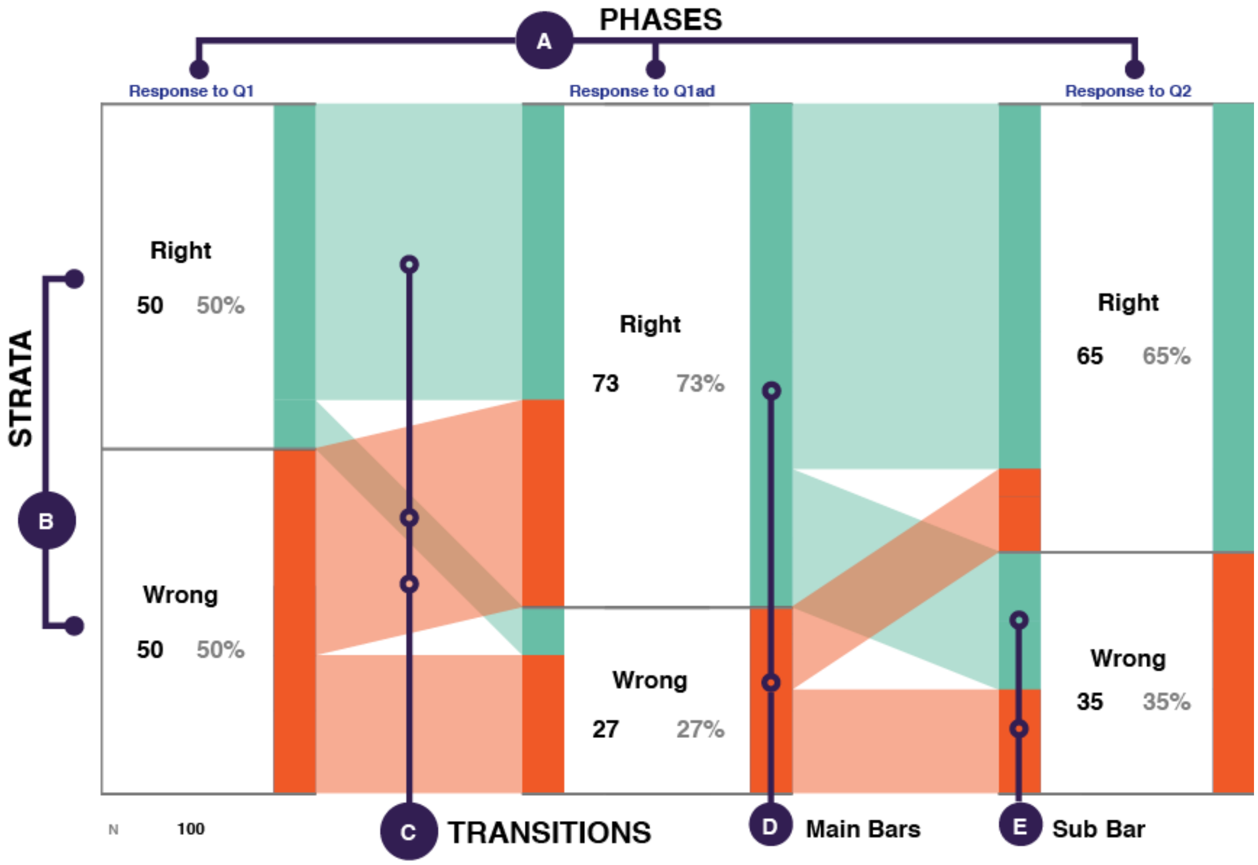


Figure 8-3 The iSAT Visualization

Table 8-5 Constructs of iSAT

Construct	Concept	Example	Mark	Channel
Phases	Each attribute in the dataset that can be stratified according to some criteria on the record's attribute can be represented as a Phase. Each Phase consists of two information; proportion of its corresponding strata and their composition with respect to the strata of the previous phase.	Each voting response set can be considered as a Phase having the Right and Wrong Strata. See 'A' in Fig 8.3	Glyph consisting of the following composite objects: bar representing its strata, labels of each strata - name of the stratum, number of records, % of records bar representing the proportion of the incoming cohort and, the bounding lines	Horizontal position: Each column of these composite item represent one Phase i.e. either an attribute or an instance of time. Multiple phases are horizontally separated in space. Vertical position: Vertically aligned bars representing strata indicate they belong to the same phase.
Strata	For some data, It is possible to group records according to any criteria set on their	Right and Wrong are the two *Strata* in the accuracy dataset. Students' response set for	Line (Bar with a fixed width)	Size: height of stratum proportional to the number of records

	attribute values. Each group of records based on a particular attribute is represented as a Stratum.	each questions can then be grouped according to the *Strata.* See 'B' in Fig 8.3		that belong to it Hue: indicates specific stratum
Transitions	Transitions between Phases represent the proportion of the records which belong to particular strata in respective phases.	Between the first voting response and the next voting response after discussion with peer, the transitions indicate the number of students who migrated from Right to Wrong or vice versa or remained in the same state of accuracy. See 'C' in Fig 8.3	Line	Width: The width of the line is proportional to the number of records in the transition that the line is representing.

8.2.2 Patterns of Transitions

A set of visualised *Transitions* across phases can represent a *Pattern.* Our example context has 3 phases each having 2 strata. Total 8 sets (2x2x2) of transition are possible. Out of them some can be grouped to form a Pattern. In our earlier work (Majumdar and Iyer, 2016) we report detailed description of the named patterns in the context of analyzing PI response data and how instructors can interpret them to take instructional decisions. We provide the relevant section from that work in Appendix II. In this section we describe the 7 named patterns with respect to the response accuracy dataset. Table 8.6 presents the pattern definitions that emerge out of the transitions of 3-phase iSAT visualization, in the context of the student's accuracy in PI responses.

Table 8-6 Patterns of Transitions in iSAT

Patterns	Description
Aligned	Cohort that remains in the same stratum across phases
Starburst	Cohort that transits from a particular stratum in a pre-phase to other more desirable strata in the post-phase
Slide	Cohort that transits from a desirable stratum in the pre-phase to a less favourable stratum in the post-phase
Returns*	Cohort that is in an initial stratum in first phase but transits to a different category in the second phase and later returns back to the original stratum
Switching	Pair of cohort that represent a switch between initial categories across consecutive phases.
Attractor	Cohort that migrates into a particular stratum in a post-phase from other strata in the pre-phase
Void	When no transitions take place between any two strata

* requires at least 3 phases

Aligned pattern: cohort remains in the same strata across phases. For example, cohort that is throughout incorrect or correct across questions, are Aligned.

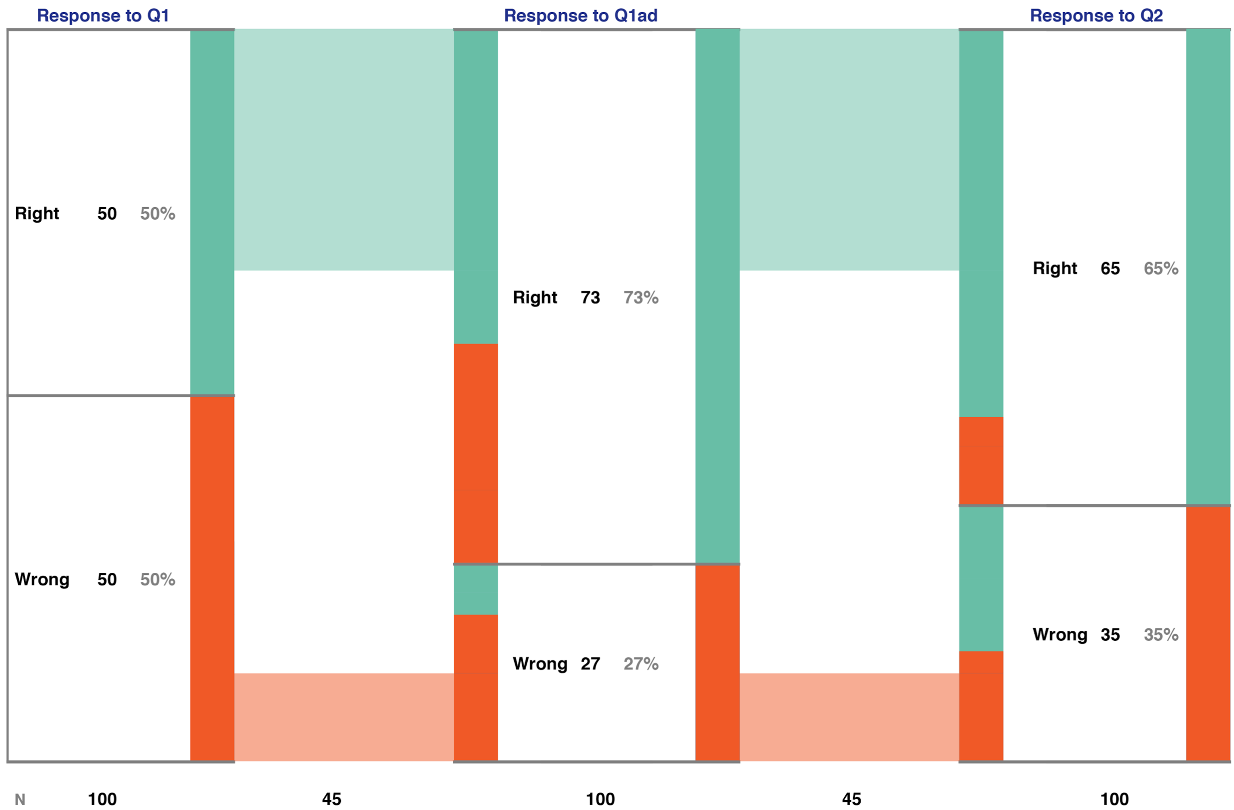


Figure 8-4 Aligned Pattern

Starbursts and Slide pattern: indicates transitions from a less desirable to a more desirable stratum while Slide is vice versa. Transitions from incorrect to correct stratum across phases is Starburst, while correct to incorrect is Slide.

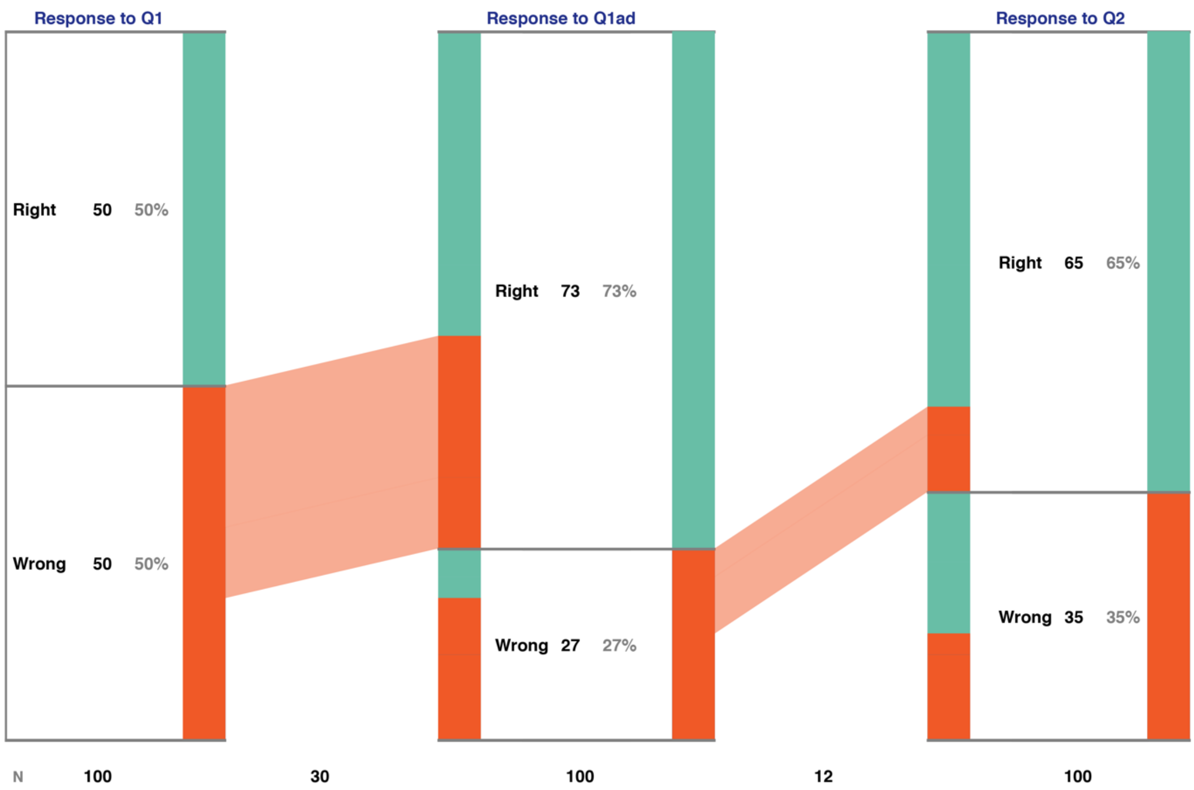


Figure 8-5 Starburst Pattern

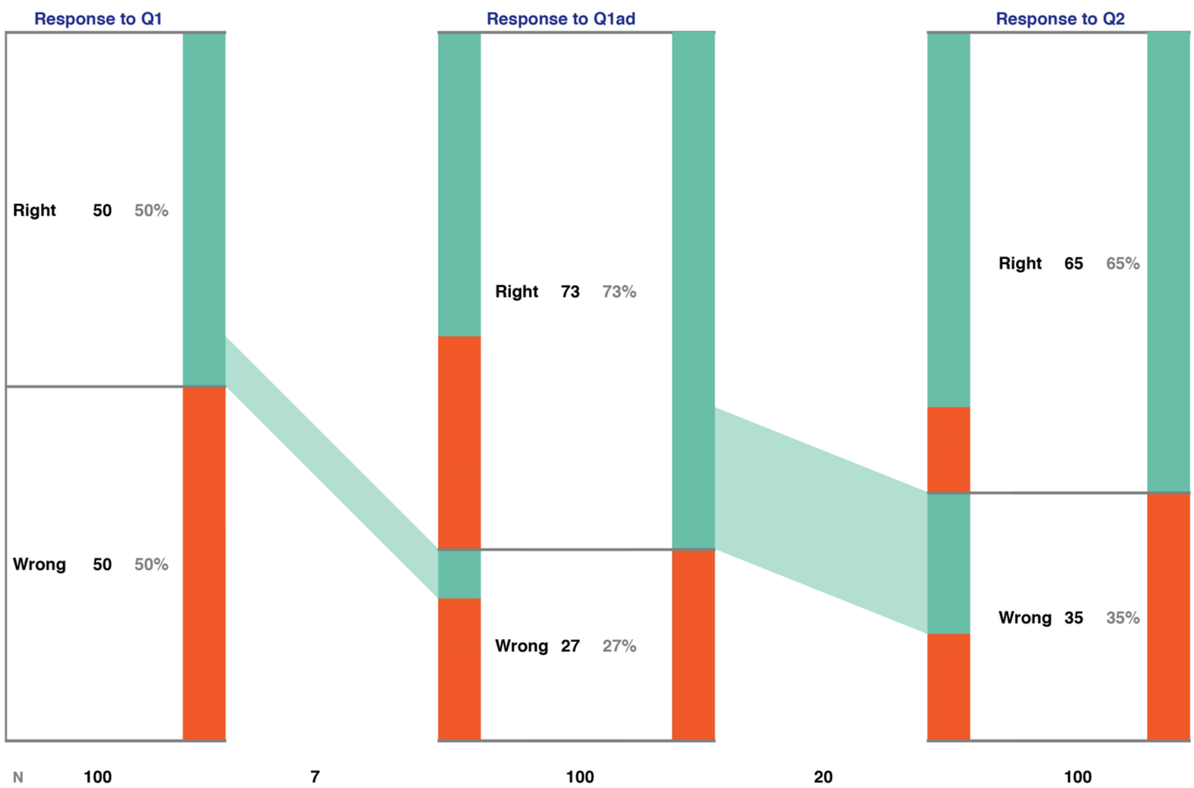


Figure 8-6 Slide Pattern

Return pattern: pattern denotes the cohort transitions that start in a stratum in the first phase and return to the same stratum in the third phase but belong to a different category in the second phase. Transitions that follow correct-incorrect-correct and incorrect-correct-incorrect across the three phases are represented by Returns.

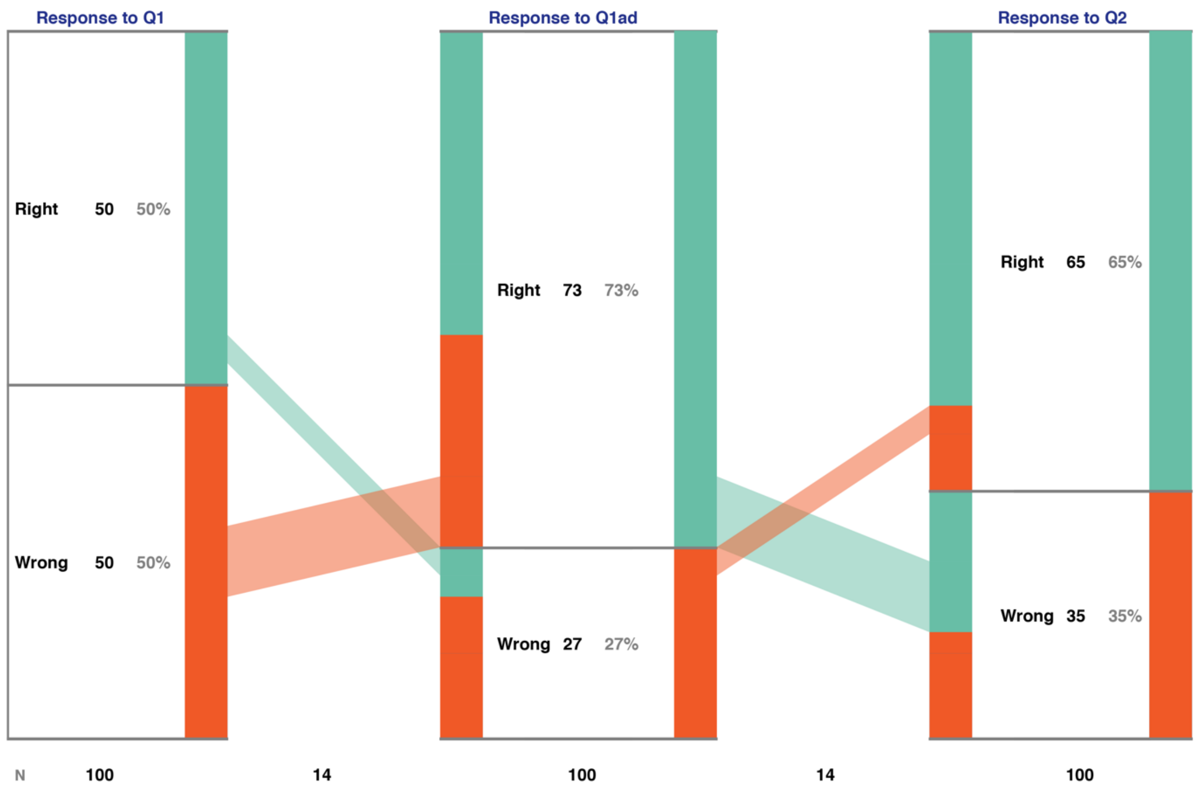


Figure 8-7 Return Pattern

Switching pattern: highlights pair of cohorts that switches between initial strata across consecutive phases. In our example there is a switching pattern between correct and incorrect strata across both the transitions.

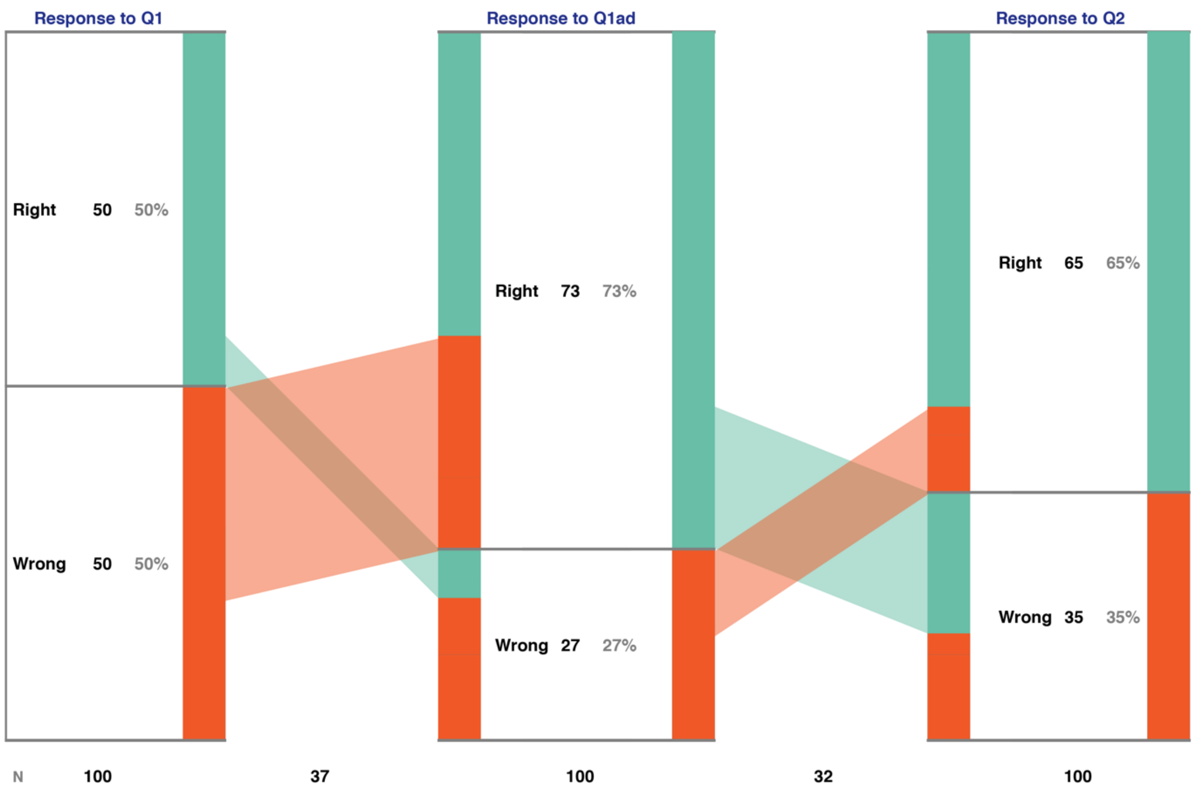


Figure 8-8 Switching Pattern

Attractor: highlights a specific stratum and visually indicates cohort that transit to that stratum from other strata in the previous phase. Attractor for 'correct' highlights the cohort transiting from incorrect to correct between consecutive phases.

Void: The absence of transitions between any two strata is defined as Void.

8.2.3 Methods to generate the meso-view with iSAT

To generate the meso-view the user first needs to define the criteria to group records in each attribute as strata. Then among the collected attributes they can choose transition across which attributes they want to trace and select those attributes as phases. To generate the information, one needs to compute the proportions for each strata in a phase and each transition among phases. iSAT visualization is a possible way to represent this information that is meant to highlight the relative proportions of each strata within phase and each transition between phases. In section 8.3 we provide a flowchart to assist users generate the meso-level view in the next section.

8.2.4 Methods to interpret the meso-view information with iSAT

With the iSAT visualization the patterns can be represented by highlighting specific sets of transitions. The analysis is defined in terms of task that the user does to search specific information at a meso-level of granularity. The Figure 8.9 provides the approach of interpreting the meso-level view. The user can conduct visual analysis by either executing a look-up task or a compare task on the visualised meso level data at one of the 4 levels. The levels are i) at stratum in a phase, ii) transition between phases, iii) patterns in a diagram, iv) overall diagram. Typically, the users can look for or compare maximum or minimum values at each level or gather specific information which is interesting as per their context. While using the tool, at each level they can get information in number of records or proportion of that cohort in percentage. The user can then use the retrieved information to interpret in the context of their data.

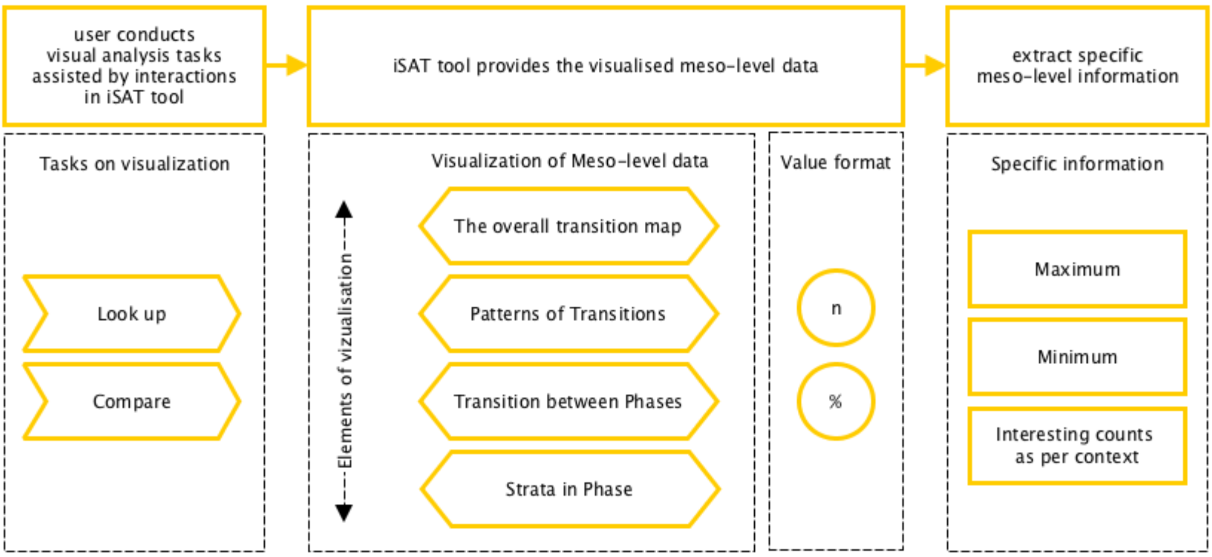


Figure 8-9 Method to analyse with iSAT

For example, at strata level one can look up what is the proportion of students who are correct after discussion. At the transition level one can compare the number of students who move from correct to incorrect state across discussion activity to the cohort which remain correct. At the pattern level one can look up the slide pattern between voting in Q1 after discussion and Q2. At the overall transition map level one can compare different instances of the PI activity between different group of students.

8.3 iSAT tool

The iSAT portal is accessible at www.et.iitb.ac.in/iSAT. The tool is accessible from the 'SATisfy your Data' button on the top right. The interface of the tool is presented in Fig. 8.10.

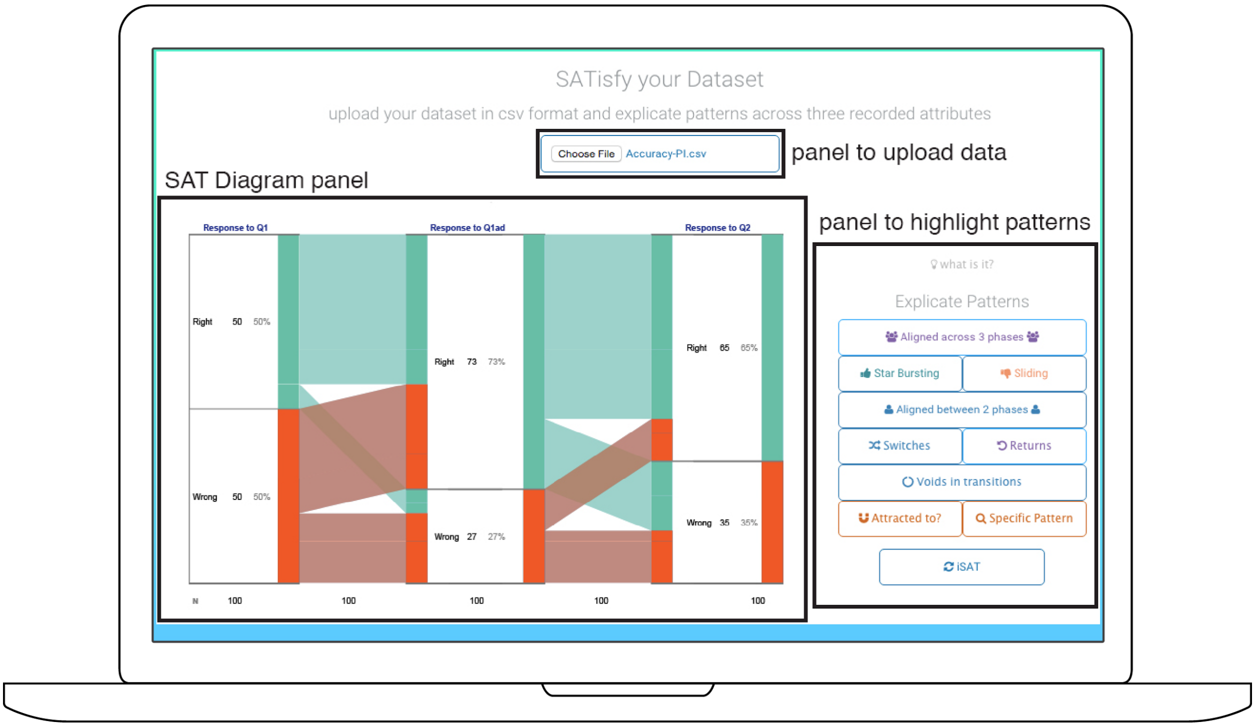


Figure 8-10 UI of iSAT tool

iSAT is an HTML/JS application which directly runs on the client browser without requiring data to be uploaded on any server. The users need to parse the data as a CSV file in a web browser (optimal experience in Google Chrome). In that CSV file, each record should be a row beginning with a primary key (unique identifier) and attributes of that record are in different columns. The attribute values are labelled to the corresponding *Strata* name that the user wants. An example of a typical data set is given in Table 8.7.

Table 8-7 Sample structure of csv file

Student Id (primary key)	**Response to Q1**	**Response to Q1ad**	**Response to Q2**
12438001	Right	Right	Wrong
12438002	Right	Right	Right
12438003	Wrong	Right	Right

Figure 8.11 shows the flowchart to determine constructs like Phases and Strata for the collected data. It also indicates how the data needs to structure in the CSV file. This CSV can then be visualised by the web-based tool. Users can follow the step-by-step workflow to determine the phases and corresponding strata of any possible iSAT visualization in their dataset. Considering the PI dataset, which has records of the form {Student ID, Response to Q1, Response to Q1ad, Response to Q2}. Response to Q1 is an attribute that the instructor chooses as the first phase. The attribute stores the accuracy of the response of each student (Right / Wrong), which is a nominal variable. Hence all the possible attribute values (Right, Wrong) are represented as strata. This completes the determination of the first phase (response to Q1) having 2 strata {'Right', 'Wrong'}. As minimum two phases are required to visualize a transition, the flow directs to choose another phase. The instructor then chooses the response after discussion (response to Q1ad). Similar to previous cycle at the end of this cycle there are 2 phases each having 2 strata. In the next cycle the instructor chooses response to Q2. Then the users need to save the data of each determined phases as consecutive columns in a CSV file with the first column as a primary key. The column heading is taken as the label for the Phase. For example, a valid CSV file to generate Fig. would have the header row as {Student ID, Response to Q1, Response to Q1ad, Response to Q2} and a sample record as {124380003, Wrong, Right, Right}.

Buttons for predefined patterns - There can be specific patterns from the list presented in Table 8.6. which can be interpreted in context of the educational setting and its data. There are buttons which highlight these named transitions. If the user wants specific pattern of transition across more than 2 phases, they can type in the name of the stratum for the consecutive phases after clicking the 'Specific Pattern' button.

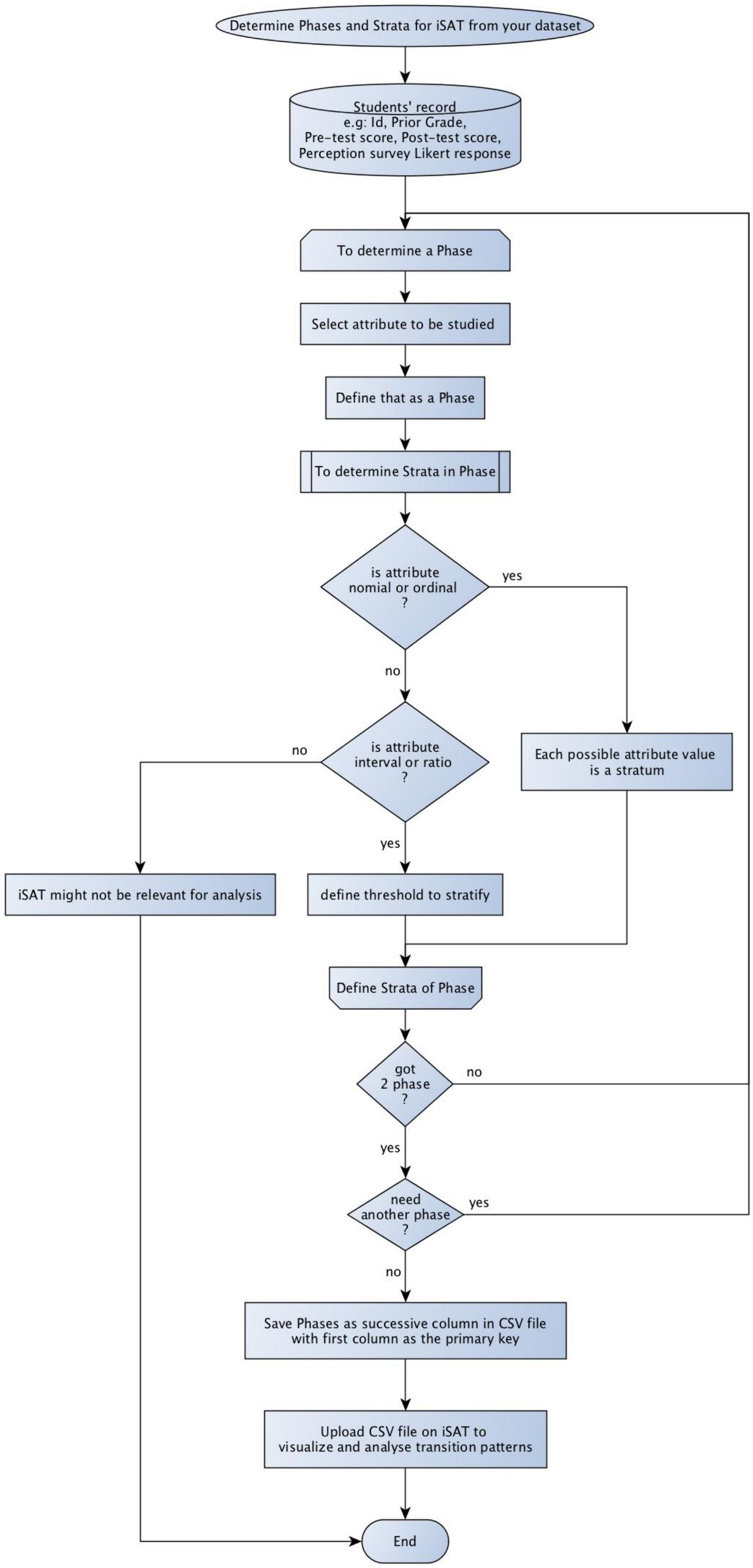


Figure 8-11 The flowchart of the method of creating data set to visualise and interact with iSAT tool

Chapter 9

Evaluation Phase: Usefulness and Applicability of iSAT

iSAT is the working solution at the end of the design and development phase. It fulfilled the research objective *to conceptualise a model and tool for visual analysis of cohorts in educational datasets.* The evaluation phase aimed at studying this generated artifact. In this chapter we report the evaluation results of usefulness, perceived usability and applicability of the developed iSAT model and tool.

9.1 Goal of the evaluation

There were 3 goals for the evaluation studies:

1. To find the usefulness and utility of the meso-level analysis with iSAT.
2. To analyse applicability of iSAT model for different educational studies.
3. To find the perceptions of first time users regarding iSAT model and tool.

In this chapter we discuss the usefulness and the applicability of iSAT. In the next chapter we give the details of the hands-on iSAT workshop and then discuss the results of the user perception studies that followed the workshops. Table 9.1 illustrates the evaluation scope with respect to the generated working model of iSAT and Figure 9.1 presents the organisation of this chapter.

Table 9-1 Evaluation scope of iSAT

Evaluation aspect	Usefulness of iSAT	Applicability of iSAT	User Perception regarding iSAT
Described In	Chapter 9		Chapter 10
Evaluation Question	What was iSAT used for? How was it useful?	In which context, for which type of RQs and for which type of data is iSAT applicable?	What is the perception of first time users regarding usefulness and usability of iSAT?
Methods / Instruments	Document analysis User interviews	Literature analysis	TAM2 survey and SUS User interviews

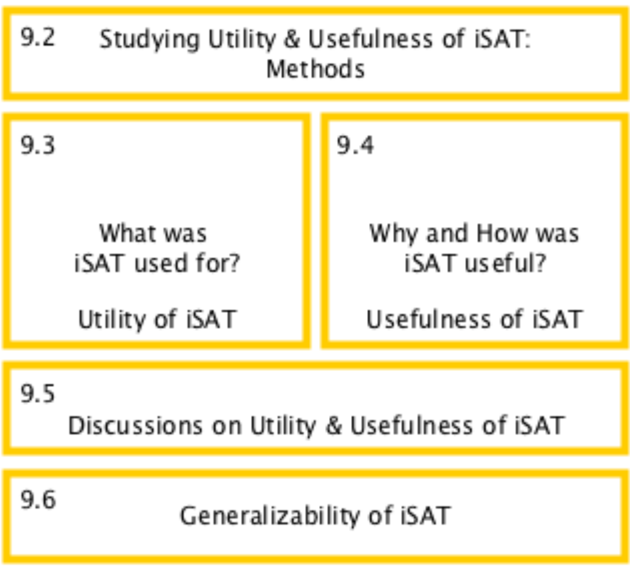


Figure 9-1 Organisation of the evaluation chapter

9.2 Studying Utility and Usefulness of iSAT: Methods

The main question of investigation was *What is the utility of iSAT and how is it useful?* (EQ 1) To answer EQ 1 inductively, I studied scenarios that applied iSAT to answer the following:

1. In which specific scenario did the user use iSAT?
2. How did the user map iSAT constructs to their context?
3. What inferences were made using iSAT?
4. How did iSAT help to analyse that scenario?

Two sources of data were collected for analysis:

1. **Manuscripts of the research reporting iSAT**: Our primary data source were the 12 manuscripts of the research that reported application of iSAT in their research scenario. Out of the 12 manuscripts, 2 of them were thesis manuscripts and the remaining were peer reviewed publications. Details are provided in Table 9.2.

   We analysed sections of text from the introduction, research methods, results and discussions from those published papers to determine 6 aspects of those studies. They were context of the study, research question(s) that were answered by iSAT analysis, research design of the study, collected data, reported meso-level view (some studies used earlier versions of iSAT), results highlighted by iSAT analysis and discussion based on the results. By analysing the above six aspects, we determine the usefulness of the iSAT constructs and meso-level analysis for each of the study. We looked into the purpose of using iSAT and grouped these multiple use cases to synthesise a utility model of iSAT for ET researchers.
2. **Researcher Interviews:** We also interviewed 6 users who used and reported their insights using iSAT model. Table 9.2 indicate the scenarios of analysis of those users. It was a semi structured interview with the focus question "*What was your context of analysis and how you use the iSAT model of meso-level analysis in that context?*" The interview data was analysed to find aspects beyond those reported in the manuscript of the published articles, such as how the user decided to use iSAT and organised their studies, how did iSAT workflow influence their analysis and what decisions did they take based on that. This helped us to further understand how iSAT was useful and nuances of its utility.

Table 9-2 The scenarios and studies that used the model of iSAT.

Scenario #	Scenario	Study	Reference
Scenario 1	Studies related to analysing TPS activities in a large enrollment lecture*	Studying engagement pattern across activity	Kothiyal et.al, 2013
		Comparing learning gains for different interventions	Kothiyal et.al, 2014
Scenario 2	Analysing students conceptual change during Peer instruction	Analysing patterns of answering to inform possible decision making	Majumdar & Iyer, 2015; Majumdar & Iyer 2016
Scenario 3	Studies to analyse students problem posing exercises (PPE).*	Difference in Novice and Expert learners during PPE	Mishra & Iyer, 2013
		Potential of PPE as Assessment	Mishra & Iyer, 2015
Scenario 4	Analysing students engineering design competency of Structuring Open Problem (SOP)*	Relation of prior achievement level vs SOP competencies	Mavinkurve, 2016 (Thesis)
		Effect of intervention on SOP competencies	
Scenario 5	Analysing trends in thinking skill development over time in a semester long course*	Impact of Project Based Learning on performance at different Bloom's level	Mistry et.al. 2016
Scenario 6	Analysing performances of early learners in a battery of phenological assessments*	Studying relationship in performance across test items and across time	Law et.al. 2016
Scenario 7	Analysing transitions of students perceptions in surveys	Probing into effectiveness of implemented framework	Majumdar & Iyer 2013
Scenario 8	Assessing learning gains in online workshops*	Studying improvement in each aspect of evaluation	Warriem et.al. 2013
Scenario 9	Analysing frustration in an intelligent tutoring system (ITS)	Probing deeper to trace impact of motivational message in ITS	Rajendran, 2014, (Thesis)

* indicates the scenarios whose researchers were interviewed to analyse utility of iSAT.

Next, we report the scenarios that used iSAT and discuss its usefulness and utility.

9.3 Results

I present details of how the iSAT model helped in each case. The scenario is described in terms of its context and questions that the users wanted to investigate in that context. For each case I give how the iSAT constructs were mapped, their visualised dataset(s) and how it assists the investigation of the context. If any of the cases used earlier version of the iSAT visualization, we present the current rendering of their dataset(s). The views from the user interview on usefulness and our interpretations are reported at the end of each case.

Table 9.3 presents the list of scenarios, corresponding to type of transition studied, the number of iSAT analysed in that context and the number of phases in those iSAT.

Table 9-3 Classification of the studies that used the model of iSAT.

		Type of transition studied	
# of iSAT analysed	# of iSAT Phases	Temporal trends	Multivariate trends
Single group / iSAT	2	Analysing students problem posing exercises (scenario 3 - study 2)	Analysing transitions of students perceptions in surveys (scenario 7)
			Assessing learning gains in online workshops. (scenario 8)
	3	Analysing engagement during TPS activities in a large enrolment lecture (scenario 1 – study 1)	Analysing students conceptual change during Peer instruction (scenario 2)
Multiple group / iSAT	2	Analysing effects on learning during TPS activities in a large enrolment lecture (scenario 1 – study 2)	Analysing trends in thinking skill development over time in a semester long course (scenario 5)
			Analysing frustration in an intelligent tutoring system (scenario 9)
			Analysing students engineering design competency of Structuring Open Problem (scenario 4 - study 1,2)
	2 and 3	Analysing performances of early learners in a battery of phonological assessments (scenario 6)	Analysing students problem posing exercises (scenario 3 - study 1)

9.3.1 Scenario 1: Studies related to analysing TPS activities in a large enrolment lecture

Think-Pair-Share (TPS) is one of the active learning (AL) strategies which was systematically implemented in the CS101 class during the Spring of 2013 at IIT Bombay. For the Computer Science Education Research (CSER) community AL techniques for large lecture class scenario concentrated mainly on Peer Discussions. So there was a need of research-based evidence from CS courses which implemented other AL techniques to achieve the instructional goals. The specific study on TPS implementation had a two-pronged research agenda:

1. to investigate the quantity and quality of **engagement** during TPS in a large CS1 course (Kothiyal et.al. 2013). This was conducted as a field study.
2. to evaluate effectiveness of TPS for **learning** (Kothiyal et.al. 2014). This was conducted as a two group experimental study.

Study 1: Tracing Engagement patterns during TPS

The engagement study during the TPS activity provided the initial context to develop analysis with State Transition Diagram, the first version of iSAT. In chapter 5 we had described details of the usefulness analysis of State Transition Diagram for this study. Table 9.4 provides the details of this context.

Table 9-4 Details of the study on tracing engagement patterns during TPS

Scenario 1	Studies related to analysing TPS activities in a large enrolment lecture	
Context	Experiments in Large UG classroom	
Study 1	Engagement during TPS in large CS 1 class	
Reference	Kothiyal A., Majumdar R., Murthy S. and Iyer S., "Effect of Think-Pair-Share in a large CS1 class: 83% sustained engagement", Proc. 9th Int. Comp. Edu. Research Workshop, August 12-14, 2013, San Diego, USA.	
Research Questions	How much students engagement occurs during the TPS activity?	How does the amount of engagement change as activity progresses?
Important of question in that context	In the context of large classroom the research investigates the engagement levels during active learning sessions. It attempts to quantify the level of engagement	understanding difference in the engagement level of each phase helps to investigate how effective the design of the activity for each phase is
RQ type	quantify	trend
iSAT #	No. 1 - Transition pattern of engagement across phases of TPS	

Attribute	*Engagement level*	
Phases ***& Strata***	*Think | Pair | Share* *Fully, Mostly, Sometimes, Never*	
# of attributes **# of Phase** **# of Strata**	1 Attribute 3 Phases 4 Strata each	
Type of analysis	temporal	
Objective	exploratory temporal trend analysis	
Analysis task	Look up desired strata in each phase	Look up transitions from full transition map
Cohort size (N)	228 students	
What did iSAT explicate?	The engagement pattern of different proportion of students were visualized across the phases of the activity. Users can compare proportion of students in each engagement level in each phase and across them. The overall pattern of engagement across the observed students in TPS activities could be summarised as a model	Visualized levels of student engagement across the phases of the activity. It highlighted significant proportion of the cohort were engaged across the phases as observed by their on-task behaviour.
iSAT Analytics affordance used	Create descriptive modelling	Comparing transitions across phases
Implications	The analysis highlighted that TPS, which evolved as a classroom intervention of regular size, can be adopted in the large classroom scenario and had desirable engagement patterns.	

Figure 9.2 provides the reconstructed iSAT diagram for the same dataset. We presented this to a researcher associated with the study and got further insights that the current version provides. The researcher agreed the current version of visualised data further represents the claim in the paper that it "gives us a complete picture of student behaviour across all phases of a typical TPS activity" (Kothiyal et.al. 2013).

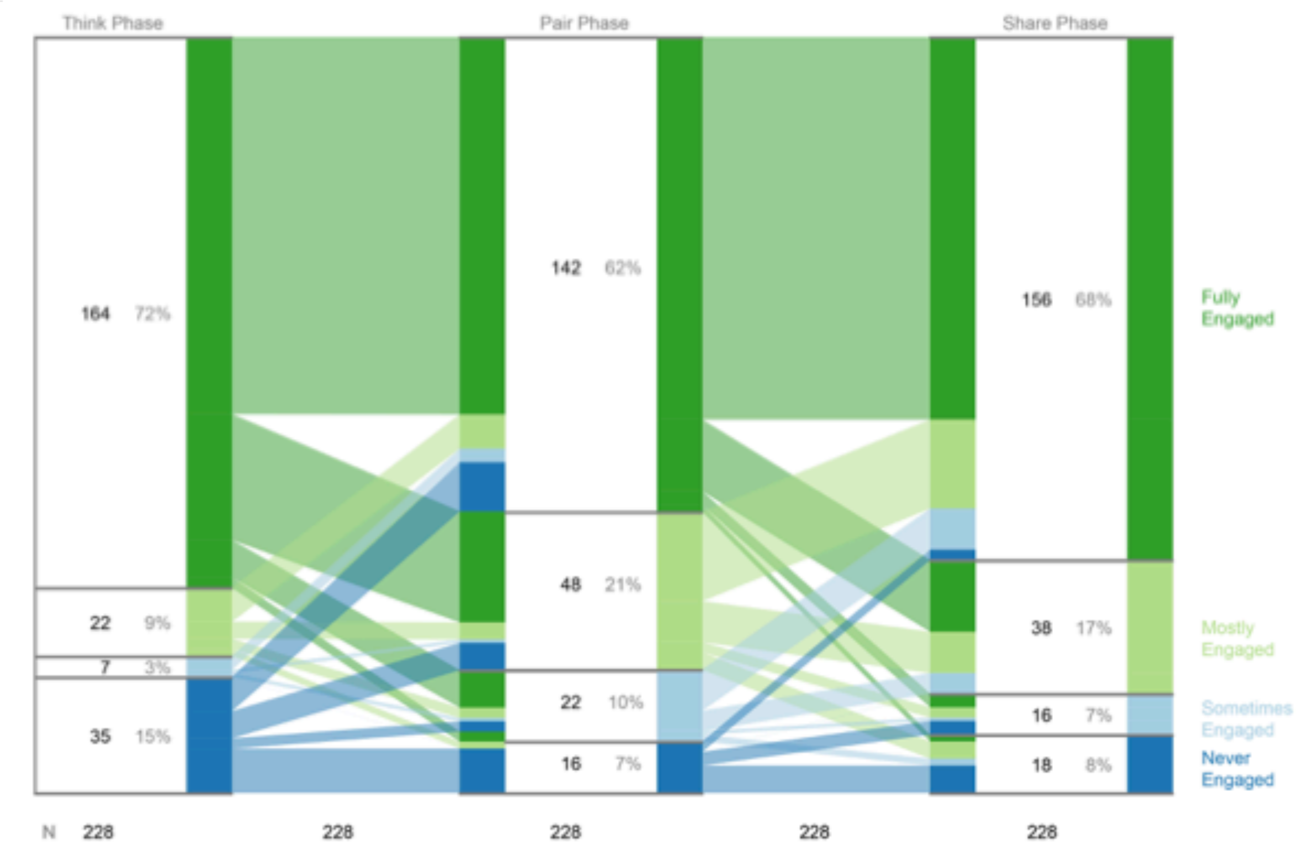


Figure 9-2 Engagement pattern across TPS activity

Study 2: Effectiveness of TPS on Learning

The relevant research question of the learning study was:
Do TPS activities lead to increased conceptual understanding and application of CS1 concepts?

Researchers conducted a two group pre-post-test quasi experimental study to determine the effectiveness of TPS over interactive lectures. Of the total cohort of 447 students in the CS101 class, randomly 263 students were assigned in the experimental group (participating in TPS activity in lecture) and 184 students to the control group (participating in interactive lecture session). The researchers established equivalence based on a pre-test on pre-requisite concepts. Then the post-test scores were significantly different for the two groups. In the interest of fairness to students the instructor conducted only 1 session different. The remainder of the semester, both the sections were taught using interactive lectures interspersed with TPS activities for maximum learning in both sections. There was no statistical difference of scores in the rest of the concept tests or the final exam performance. To understand these results further the researchers wanted to stratify the learner group according to performance and then analyse which of those groups could benefit more from the TPS activity. Table 9.5 provides the details of this context.

Table 9-5 Details of the study on studying effectiveness of TPS on learning

Scenario 1	Studies related to analysing TPS activities in a large enrolment lecture	
Context	Experiments in Large UG classroom	
Study 2	Learning effect of TPS in large CS 1 class	
Reference	Kothiyal, A., Murthy, S., & Iyer, S. (2014). Think-pair-share in a large CS1 class: does learning really happen?. In Proceedings of the 2014 conference on Innovation & technology in computer science education (ITiCSE '14). ACM, New York, NY, USA, 51- 56.	
Research Questions	Do TPS activities lead to increased conceptual understanding and application of CS1 concepts?	
Important of question in that context	In order to find out which group of learners are most affected in an active learning intervention	
RQ type	Disproportion	
***iSAT* #**	No. 2 - Transition pattern of performance for group exposed to interactive lectures (control group)	No. 3 - Transition pattern of performance for group exposed to TPS activity (experimental group)
Attribute	*Achievement score*	
Phases & Strata	*Pre-Test score | Post-Test score* *High, Medium, Low*	
# of attributes **# of Phase** **# of Strata**	1 Attribute 2 phases 3 strata in each phase	
Type of analysis	temporal	
Objective	exploratory temporal trend analysis	
Analysis task	Compare 2 transition map	
Cohort size (N)	169 students in control group	250 students in experimental group
What did iSAT explicate?	The transition patterns between Pre-test and Post-test were visualised for two groups, one who was engaged in TPS activities and other participating in an interactive lecture session. User contrasted achievement levels of the two groups and found more students in the active learning groups improved in Post-test than students who participated in interactive sessions.	
iSAT Analytics affordance used	compare - across iSAT	
Implications	Conducting TPS positively affect students learning and interactive lectures did not affect	

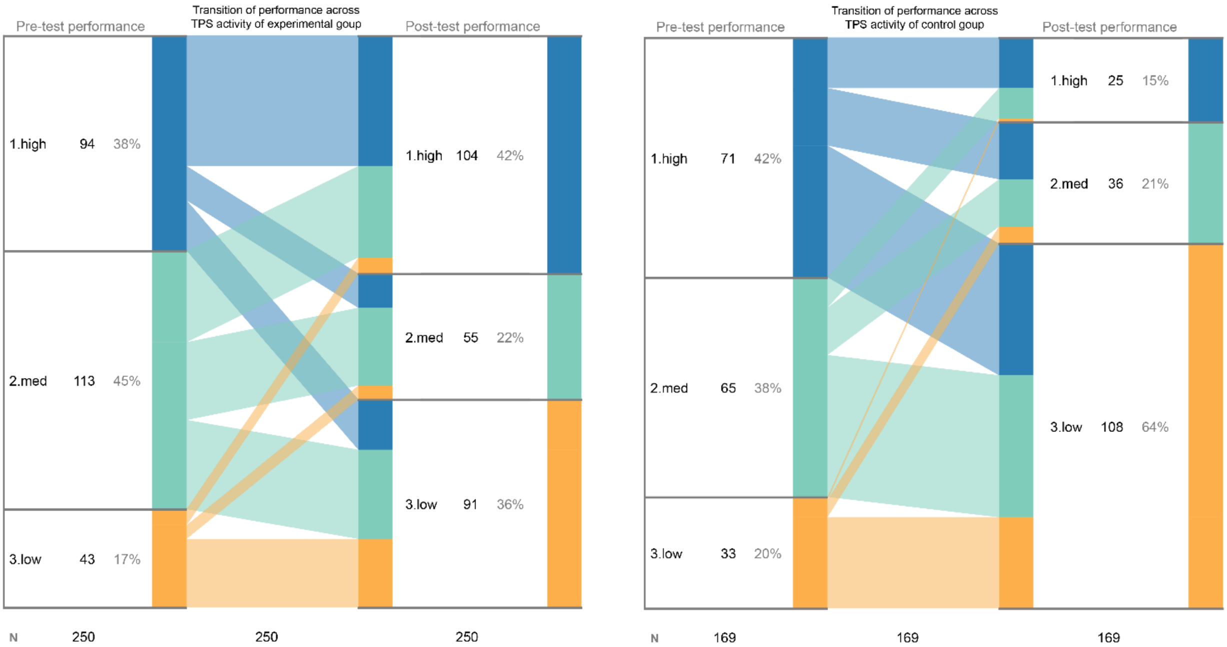


Figure 9-3 Transition patterns in performance of experimental (TPS activity) and control (interactive lecture) group

The iSAT model enabled researchers to look at the transition patterns of the participants in each control and experimental groups across the two Phases: pre-test and post-test. Strata represented the performance level grouping into High-Medium-Low (H-M-L) in each Phase. The iSAT visualisations (Figure 9.3) “show that a majority of students in the experimental group transitioned into equal or higher performance level from the pre-test to the post-test. In the control group however, students moved into lower performance levels”. Based on that the researchers could conclude “TPS activity enabled students of all categories in the experimental group to perform better on the post-test as compared to the students in the control group.”

9.3.2 Scenario 2: Analysing students conceptual change during Peer instruction

Our first scenario highlighted that research trends could be analysed by the iSAT model. Next I examined how an instructor could benefit from tracing transitions across stratified attributes and studied peer instruction (PI), another active learning strategy. We also introduced the iSAT tool which would enable the instructor to conduct any analysis in real time. Though field study of this implementation is pending, we could heuristically study how possible instructional decisions can be taken by analysing sub groups in the class.

Researchers initially were interested to analyze only aggregate-level learning gain during such activities (Hake, 1998). Later, others (Smith et al. 2009; Porter et al. 2011) analyzed transitions of accuracy across attempts by using flowcharts. It is to be noted that the transitions among alternate conceptions, as reflected by responses across the two attempts, are not highlighted. It is interesting to observe those transitions (Wittmann and Black 2014) as they help to decide post-discussion activities (Majumdar and Iyer 2015).

iSAT model is useful for such analysis to trace transition patterns across the voting Phases (see visualised sample data in figure 9.4). The Strata represents the various categories of response associated with the question. After the transitions are visualised the patterns that iSAT highlights can assist instructional decision making. For example, Switching patterns between incorrect responses highlight that 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. Details of the other 6 patterns, the corresponding interpretation in the context of analysing PI response and the instructional decision is given in Appendix C.

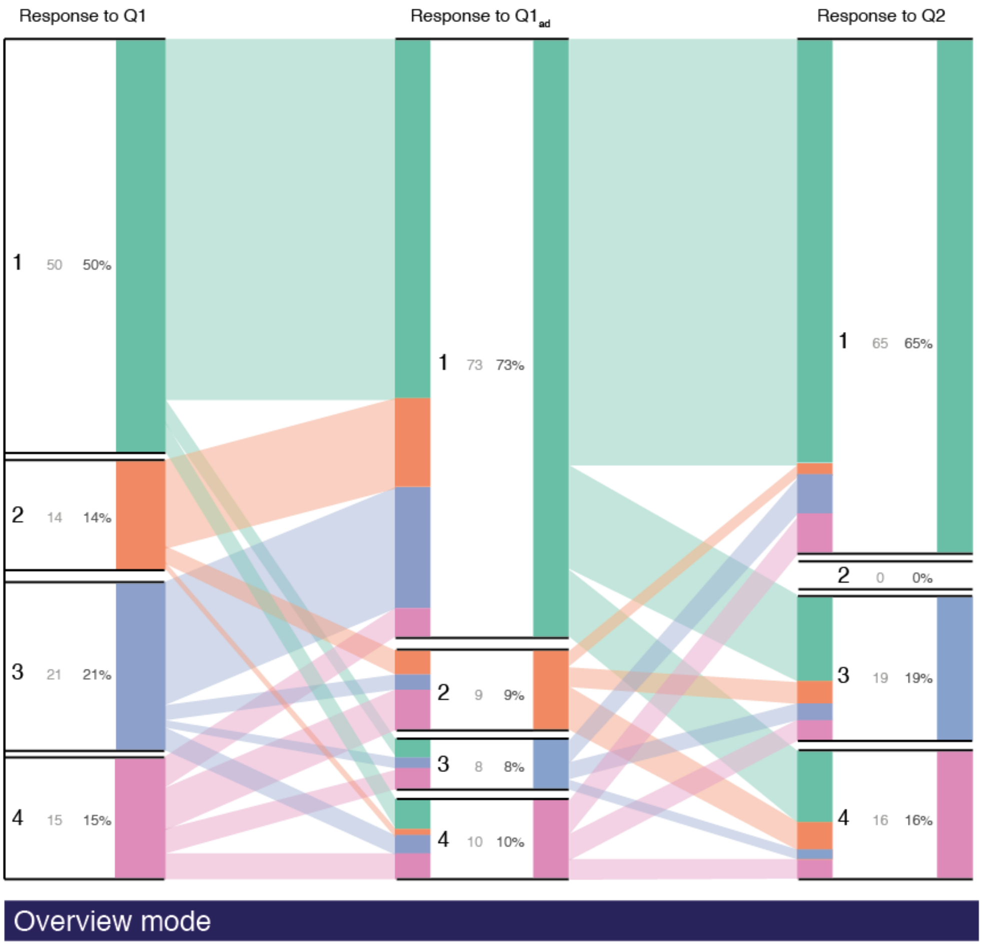


Figure 9-4 Transitions in voting response across PI with isomorphic question

Table 9-6 Details of the context of PI analysis

Scenario 2	Analysing students conceptual change during Peer instruction
Context	Face to face Classroom
Study 3	Analysing patterns of answering to inform possible instructional decision making.
Reference	Majumdar R. & Iyer S. (2016) iSAT: a visual learning analytics tool for instructors, Research and Practice in Technology Enhanced Learning, 11(1), 1-22 Majumdar, R., & Iyer, S. (2015). Beyond clickers: tracing patterns in students' response through iSAT. In Procs. of Intnl. Conf on Computers in Education (ICCE 2015), Hangzhou, China.
Research Questions	How does the learners answering pattern change during the PI activity?
Important of question in that context	To assist decision making of post PI activity instructional strategy
RQ type	Analyse trend
***iSAT* #**	No. 4 - Transition pattern of voted response of students during PI activity
Attribute	*Voted answer*
Phases & Strata	*Q1| Q1-after discussion | Q2* *Option A,B,C,D*
# of attributes **# of Phase** **# of Strata**	1 Attribute 3 phases 4 strata in each phase
Type of analysis	Temporal + Multivariate
Objective	Analyse answering patterns in PI datasets
Analysis task	Compare 2 transition map
Cohort size (N)	Generated voting response of 100 students
What did iSAT explicate?	Learners chose answer option in each phase. iSAT visualized transitions in learners response across those different voting phases. If the options were linked to each alternate conceptions in that specific topic then iSAT highlights the change in conception for each group of students.
iSAT Analytics affordance used	descriptive modelling
Implications	The trend analysis would give an overview of the alternate conceptions students in a class have. Based on that trend the instructor can take instructional decisions.

9.3.3 Scenario 3: Studies to analyse students' problem posing activities.

Problem posing refers to the generation of a new problem or a question based on the given situation (Toluk-Uçar Z.,2009). The current context studied a pairwise Problem posing exercise (PPE) in CS1 lab. Researchers wanted to investigate multiple aspects of PPE based on the field study in a large enrolment undergraduate class. The first one focused on finding difference in the effects of PPE for novice and advanced learners. The second one investigated the potential to use PPE as an assessment tool.

In a class of 450 students, researchers classified novice and advanced students based on a demographic survey asking whether they had exposure to programing (advanced) or not (novice). 332 students completed the survey and there were 217 novice learners and 115 advance learners. There were random pairing totalling 135 pairs to analyse. If both members were novice learners then only the pair was tagged as novice else if either or both members were advanced learners, it was an advanced pair. Each pair is considered as a sample. A pre-test and post-test was conducted a week before and after the PPE respectively. After evaluating the tests, each group was given the average of the marks of its two members. During the lab session each pair generated 2 problems together. The researchers evaluated the difficulty of the two problems based on a validated rubric and aggregated the quality of problem posed by that sample. Problems generated by 60 novice and 62 advanced pairs were selected for analysis.

Study 1: Investigate differences in effect of PPE for advanced and novice groups

The specific research question for which iSAT was used are the following:
RQ1- How does PPE affect students' learning outcome (as measured by tests) in CS1 course?
RQ2 - What is the transition pattern from - pretest performance - to - posttest performance of novice and advanced learners, as a result of the PPE activity?

To answer RQ1 related to effectiveness of PPE on students' learning, the researcher looked at the gain in the aggregated pre-test and post-test scores of the 135 samples. But the difference was not statistically significant. So he grouped the cohort based on the rubric score of difficulty of the questions that they generated and zoomed into the performance gain in each difficulty group (H-M-L). Though there were improvement in post test score in each category, this too did not indicate any statistical differences.

The performance level of those 135 group sample was then stratified as High-Medium-Low for both pre and post-test. The transition pattern between the pre and post-test is given in Figure 9.5 and it highlights the proportion of learners who improved. Table 9.7 provides the details of this context.

Table 9-7 Details of the study on effects of PPE on students' learning outcome

Scenario 3	Studies to analyse students problem posing exercises (PPE).
Context	Experiments in face to face workshop
Study 4	Difference in Novice and Advanced learners during PPE.
Reference	Mishra S. & Iyer S. (2013) Problem Posing Exercise (PPE): An instructional strategy for learning of complex material in introductory programming courses. In Proceedings of the IEEE 6th International Conference on Technology for Education (T4E, 2013), 151-158.
Research Questions	How does PPE affect students learning outcome (as measured by tests) in CS1 course?
Important of question in that context	The investigation finds out which group of learners are most affected in an active learning intervention
RQ type	Consequence
iSAT #	No. 5 - Transition pattern of students performance between pre and post tests
Attribute	*Assessment score*
Phases & Strata	*Pre-Test score | Post-Test score* *High, Medium, Low*
# of attributes # of Phase # of Strata	1 Attribute 2 phases 3 strata in each phase
Type of analysis	Temporal
Objective	Exploratory temporal trend analysis
Analysis task	Look up desired pattern of transition - starbursts
Cohort size (N)	Performance of 135 groups
What did iSAT explicate?	Visualised transition patterns between Pre-test and Post-test for the whole group of students. It was evident that students improved or retained their performance level after the question posing exercise.
iSAT Analytics affordance used	Descriptive modelling
Implications	The analysis illustrated the positive effect of question posing to improve performance of majority of the students in each achievement cohort.

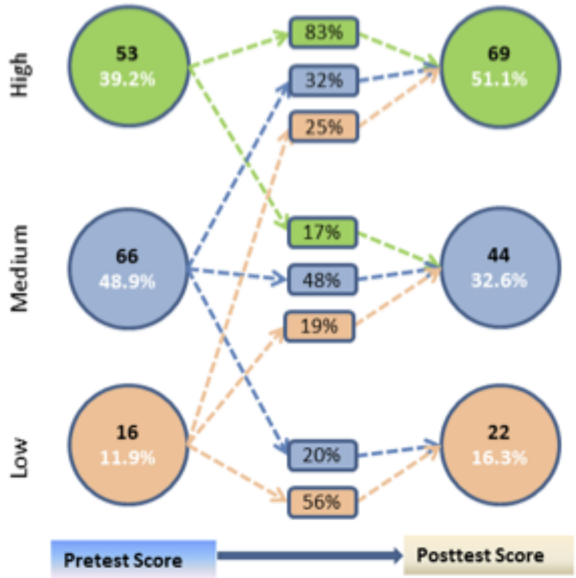


Figure 9-5 Transitions in performance between Pre and Post test

The researcher could conclude "The probability that any student remains in the same performance level or improves his performance is significantly higher than the probability that he/she reduces his/her performance. In 112 samples out of total 135 samples, it is evident that students improved or retained their performance." iSAT model assisted the researcher to quantify the impact based on stratification and tracking the performance.

To answer RQ2, the researcher traced the transition pattern from performance in pre-test to the level of question difficulty generated to the post test performance. The details of the iSAT analysis is given in Table 9.8. The transitions were traced for both the Novice (Figure 9.6) and Advanced learners (Figure 9.7).

Table 9-8 Details of the study on effects of PPE on Novice and Advanced learners

<table>
<tr><th>Scenario 3</th><td colspan="2">Studies to analyse students problem posing exercises (PPE)</td></tr>
<tr><th>Context</th><td colspan="2">Experiments in face to face workshop</td></tr>
<tr><th>Study 4</th><td colspan="2">Difference in Novice and Advanced learners during PPE.</td></tr>
<tr><th>Reference</th><td colspan="2">Mishra S. & Iyer S. (2013) Problem Posing Exercise (PPE): An instructional strategy for learning of complex material in introductory programming courses. In Proceedings of the IEEE 6th International Conference on Technology for Education (T4E, 2013), 151-158.</td></tr>
<tr><th>Research Questions</th><td colspan="2">- What is the transition pattern from - pretest performance - to - posttest performance of novice and advanced learners, as a result of the PPE activity?</td></tr>
<tr><th>Important of question in that context</th><td colspan="2">The investigation finds out which group of learners are most affected in an active learning intervention</td></tr>
<tr><th>RQ type</th><td colspan="2">Disproportion</td></tr>
<tr><th>iSAT #</th><td>No. 6 - Transition pattern of performance for novice group</td><td>No. 7 - Transition pattern of performance for advanced group</td></tr>
<tr><th>Attribute</th><td colspan="2">Achievement score
Difficulty level</td></tr>
<tr><th>Phases & Strata</th><td colspan="2">Pre-Test score | Rubric score | Post-Test score
High, Medium, Low</td></tr>
<tr><th># of attributes
# of Phase
# of Strata</th><td colspan="2">2 Attribute
3 phases
3 strata in each phase</td></tr>
<tr><th>Type of analysis</th><td colspan="2">Multivariate + temporal</td></tr>
<tr><th>Objective</th><td colspan="2">exploratory multivariate trend analysis</td></tr>
<tr><th>Analysis task</th><td colspan="2">Compare 2 transition map</td></tr>
<tr><th>Cohort size (N)</th><td>60 novice learner group</td><td>62 advanced learner group</td></tr>
<tr><th>What did iSAT explicate?</th><td colspan="2">"Visualized proportion of difficulty level of the student generated problems and the transitions of test performances for those students.
It helped to assess effectiveness of the PPE based instruction for novice and advanced learners group. Transition patterns show that PPE had more visible effects on novice learning outcome and not on Advanced Learners'.
Without any explicit training on PP, Medium level difficulty questions are more posed by both high and medium level pretest performers in both novice and advanced cases. Interestingly advanced learners generate more low level questions than Novices.
Higher the difficulty level of generated problem, higher is the posttest score; but it does NOT necessarily imply that: lower difficulty yields lower posttest performance."</td></tr>
<tr><th>iSAT Analytics affordance used</th><td colspan="2">compare - across iSAT</td></tr>
</table>

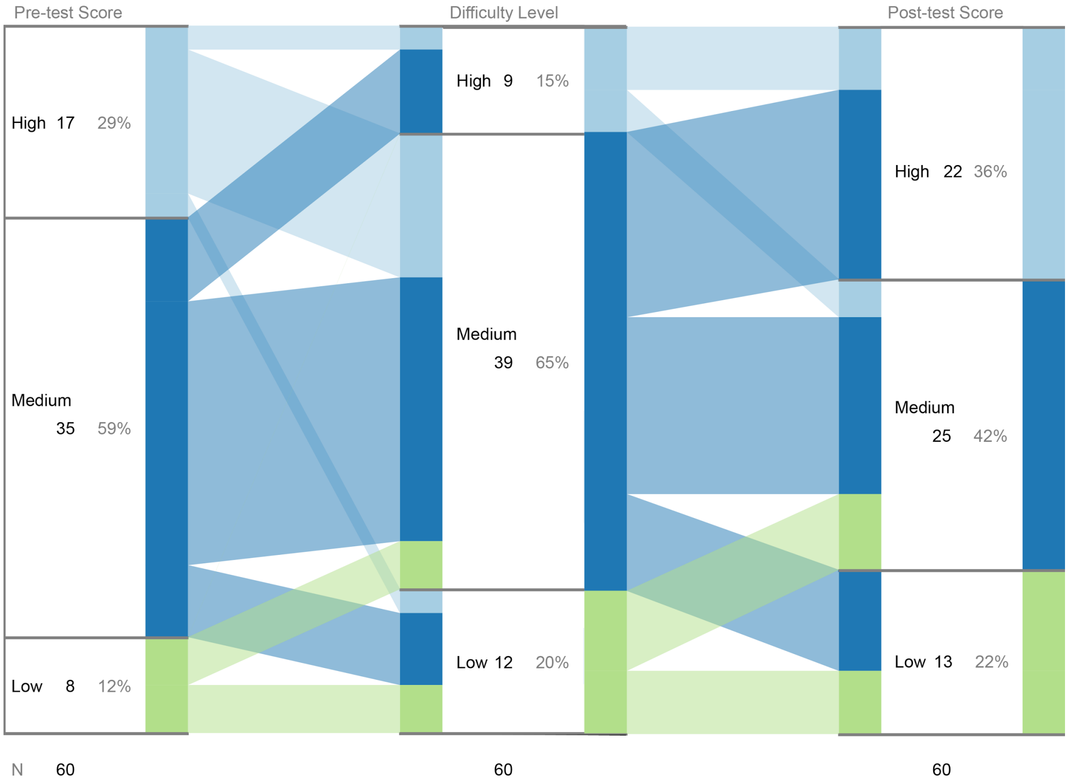


Figure 9-6 Novice learner transition pattern across
Pre-test :: Difficult level of generated question :: Post test

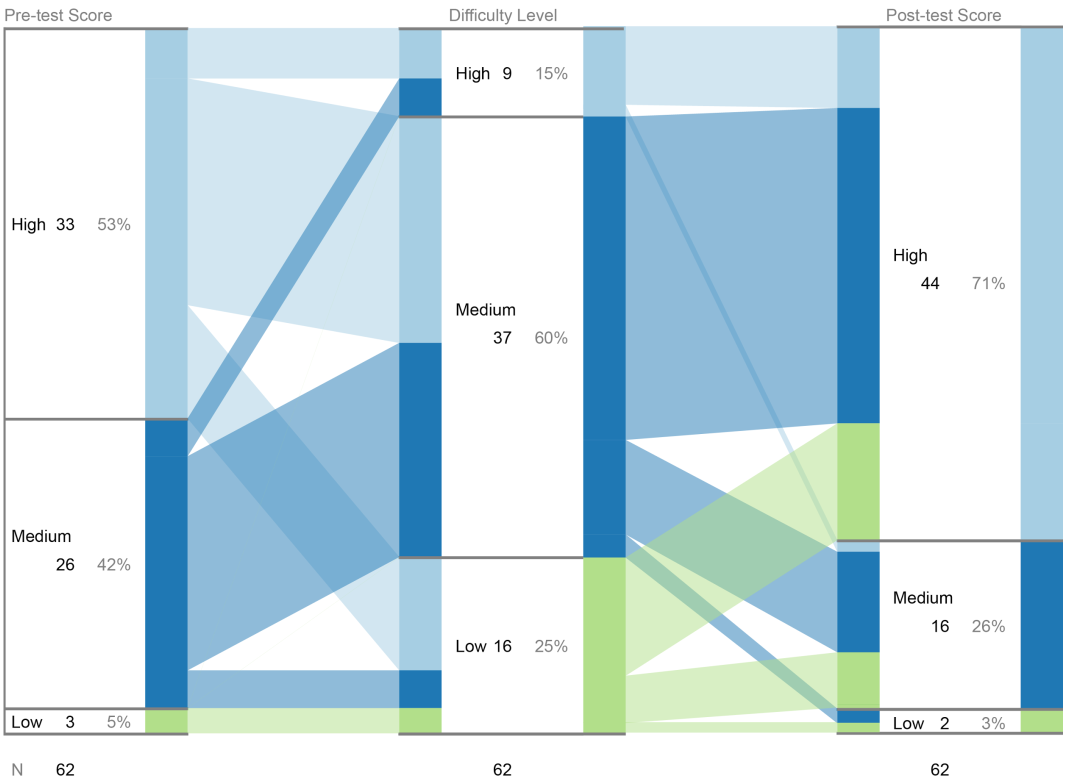


Figure 9-7 Advanced learner transition pattern across
Pre-test :: Difficult level of generated question :: Post test

The researcher concluded the following after analysing the above transition patterns of Novice and Advanced learners:

- Transition patterns show that PPE had more visible effects on novice learning outcome and not on Advanced Learners.
- Without any explicit training on Problem Posing(PP), medium level difficulty questions are more posed by both high and medium level pre-test performers in both novice and advanced cases.
- An interesting observation was that advanced learners generate more low level questions than novices.
- Higher the difficulty level of generated problem, higher is the post-test score; but it does NOT necessarily imply that: lower difficulty yields lower post-test performance

Study 2: Investigate assessment potential of PPE

The objective of the study was to investigate how a non-traditional assessment like PPE can be used for the purpose of differentiating High-Med-Low achievers as indicated by traditional assessments. The specific research question that iSAT was used was the following:

How does the quality of question(s) generated by a student relate to the score achieved by him/her in the traditional assessment?

The analysis just focused on the transition between the Pre-test score and the level of question difficulty for both the groups. Details are provided in Table 9.9

Table 9-9 Details of the study to investigate assessment potential of PPE

Scenario 3	Studies to analyse students problem posing exercises (PPE).	
Context	Experiments in face to face workshop	
Study 5	Potential of PPE as Assessment	
Reference	Mishra, S., & Iyer, S. (2015). An exploration of problem posing-based activities as an assessment tool and as an instructional strategy. Research and Practice in Technology Enhanced Learning, 10(1), 5.	
Research Questions	How does the quality of question(s) generated by a student relate to the score achieved by him/her in the traditional assessment?	
Important of question in that context	to test the correlation between two assessment scores for different strata of students	
RQ type	relation	
iSAT #	No. 8 - Transition pattern of performance for novice group	No. 9 - Transition pattern of performance for advanced group
Attribute	Achievement score Difficulty level	
Phases & Strata	*Pre-Test score | Rubric score* *High, Medium, Low*	
# of attributes # of Phase # of Strata	2 Attribute 2 phases 3 strata in each phase	
Type of analysis	Multivariate + temporal	
Objective	exploratory multivariate trend analysis	
Analysis task	Compare 2 transition map	
Cohort size (N)	60 novice learner group	62 advanced learner group

What did iSAT explicate?	Only in the Advanced learner group, higher proportion of high performers generated low difficulty question. The novice learners were more aligned in their performance level and the difficulty of the questions they generated. This shows that the difficulty level can be used to assess the learning of novices, but not advanced learners.
iSAT Analytics affordance used	descriptive modelling

Figure 9.8 provides the iSAT visualisation for the two groups: a) Novice and b) Advanced. Based on which the researcher then concluded the following:

“Interestingly, high probability of generating low difficulty questions by high pre-test performers is evident in the case of advance learners only his shows that the difficulty level can be used to assess the learning of novices, but not for advanced learners.”

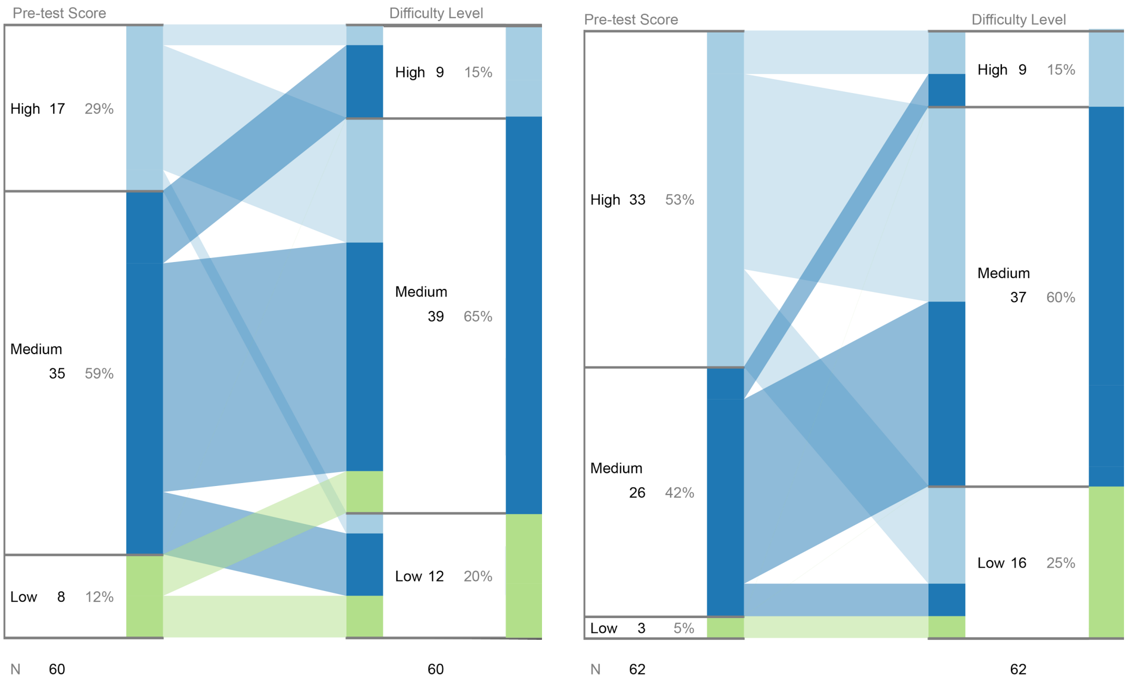


Figure 9-8 Transition pattern between Traditional performance (Quiz) score and non-Traditional performance (difficulty of question rubric score) for Novice & Advanced group

9.3.4 Scenario 4: Analysing students engineering design competency of Structuring Open Problem (SOP)

Structured Open Problem (SOP) is an engineering design competency. A researcher was developing a Technology Enabled Learning Environment (TELE) to assist students learn four of the associated sub competencies. These sub-competenciesx are the following:

SOP 1) Identify specifications from given open ended problem.
SOP 2) Decide structure based on specifications.
SOP 3) Implement design steps sequentially.
SOP 4) Write problem statement in structured manner.

The learning system was named TELE-EDesC. The system provides learning dialogues such as Decision-Making Task Questions, Simulative Manipulations, Concept Clarification Questions, Self-assessment rubrics, Controlled Animation, Capsule Recommendations and Information Box that the students interact with to develop the competency.

Study 1: Evaluate learning effectiveness of TELE-EDesC

While evaluating TELE-EDesC the researcher wanted to understand the relation between students' prior knowledge level and success in attaining SOP competency. Prior analysis established effective intervention design as indicated by significant statistical difference between the intervention group and the control group. The researcher further categorised the data according to high, medium and low performers in pre-test and then looked at each of the SOP competency for the experimental group. There was no statistically significant difference in their performance across the SOPs for any of the HML performance group. So the researcher wanted to probe further and find *who* was successful in attaining each SOP competency after the TELE-EDesC intervention. They wanted to answer queries like the following: "How many low achieving students were successful in attaining SOP competency", or, "Students from which prior knowledge achievement level make up the 'successful' category in SOP?. iSAT model assisted in conceptualising this information by representing the Phases as Prior Achievement and SOP competencies. The Strata for the Prior Achievement were Low, Medium or High based on the Pre-test score of the learners. The Strata in the SOP competency was Unsuccessful or Successful based on their task. Details of the iSAT analysis is provided in Table 9.10. The SAT diagram of the relationship between prior knowledge achievement level and success in SOP competency for all the four sub competencies is presented in Figure 9.9.

Table 9-10 Details of the study to investigate learning effectiveness of TELE-EDesC

Scenario 4	Analysing students engineering design competency of Structuring Open Problem (SOP)
Context	Experiments in face to face workshop
Study 6	Relation of prior achievement level vs SOP competencies.
Reference	Mavinkurve, M. (2016) Development and assessment of engineering design competencies using technology enhanced learning environment. Thesis
Research Questions	What is the relation between students' prior knowledge level and success in attaining SOP competency?
Important of question in that context	to test the effect of prior knowledge on attainment of SOP competency for different strata of students
RQ type	21a. conjunction
iSAT #	No. 10 to No 13 : Transition pattern of prior performance to competencies in SOP 1 to 4
Attribute	Achievement score SOP competency
Phases & Strata	*Prior Achievement | SOP competency* *High, Medium, Low || Successful, Unsuccessful*
# of attributes # of Phase # of Strata	2 Attribute 2 phases 3 strata in prior achievement and 2 in SOP competency
Type of analysis	Multivariate
Objective	exploratory multivariate trend analysis
Analysis task	Look up patterns of transition - compare each of the 4 SOP competencies
Cohort size (N)	90 students
What did iSAT explicate?	Visualised transitions of cohorts in prior achievement levels to their SOP competency. Separately diagrams were visualized for each of the 4 SOP competencies. "More number of students were categorised as successful students on SOP sub-competencies SOP1, SOP2 and SOP3. But for SOP4 it was found that a large fraction from experimental group students were unsuccessful. This was true of students from all prior achievement levels leading to a conclusion that students' prior achievement level did not play a role in the attainment of SOP competency
iSAT Analytics affordance used	taking research decision based on comparing descriptive pattern
Implications	This analysis directed the redesign exercise of TELE-EdesC where the researcher focused only on items related to SOP 4.

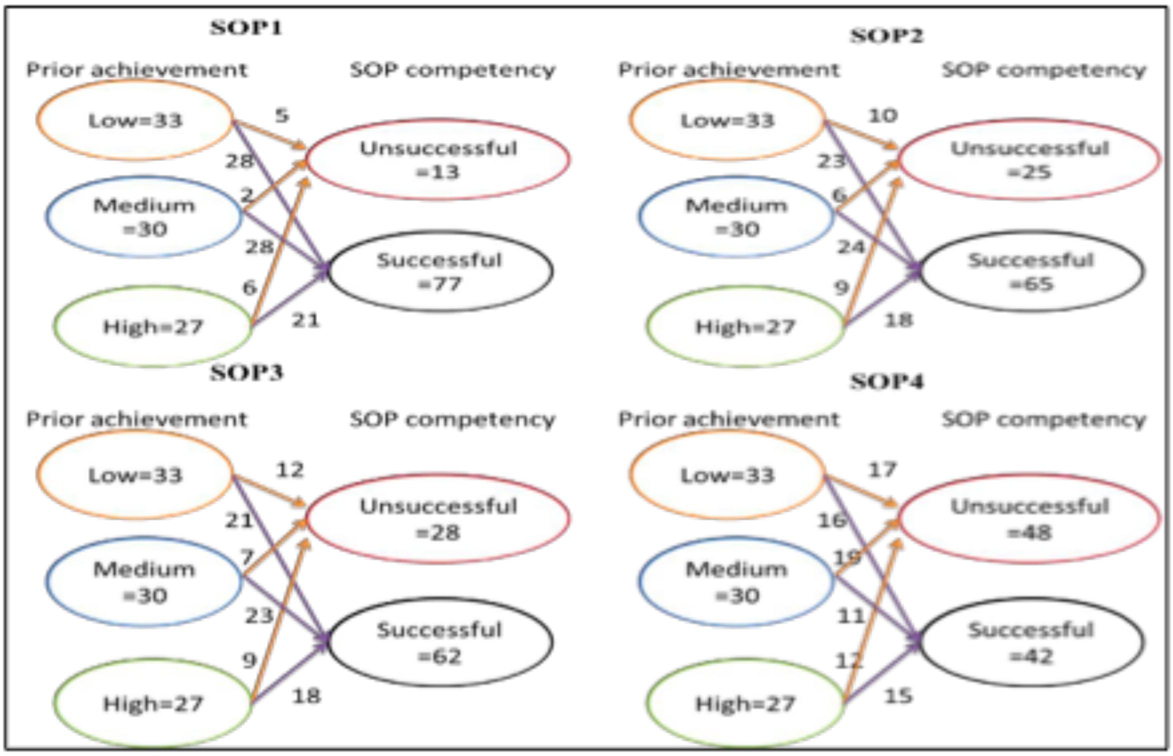


Figure 9-9 SAT diagram showing relation between prior knowledge achievement level and success in SOP competency

The analysis highlighted "more number of students were categorised as successful students on SOP sub-competencies SOP1, SOP2 and SOP3. But for SOP4 it was found that a large fraction from experimental group students were unsuccessful. This was true of students from all prior achievement levels leading to a conclusion that students' prior achievement level did not play a role in the attainment of SOP competency."

Based on the observation in the analysis, the researcher made design change in TELE-EDesC to further support developing of sub competency SOP4. The new theory informed change provided the learners with a self-assessment rubric along with TELE-EDesC.

Study 2: Learning effectiveness study of revised TELE-EDesC

The researcher designed a two-group experimental design to find the effectiveness of the new design of intervention. SAT visualization helped to visualise learner's group membership and transitions to their on-task success for each individual sub competencies (see Figure 9.10). The details of the iSAT analysis is presented in Table 9.11

Table 9-11 Details of the study to investigate effectiveness of revised TELE-EDesC

Scenario 4	Analysing students engineering design competency of Structuring Open Problem (SOP)
Context	Experiments in f2f Classroom
Study 7	Effect of intervention on SOP competencies
Reference	Mavinkurve, M. (2016) Development and assessment of engineering design competencies using technology enhanced learning environment. Thesis
Research Questions	What are the patterns of the students success in the design task after the redesign of the TELE-EDesC?
Important of RQ in that context	to test the effect of prior knowledge on attainment of SOP competency for different strata of students
RQ type	33a. consequence
iSAT #	No. 14 to No 17 : Transition pattern of intervention group to competencies in SOP 1 to 4
Attribute	Intervention group SOP competency
Phases & Strata	*Group | SOP competency* *Control, Experimental || Successful, Unsuccessful*
# of attributes # of Phase # of Strata	2 Attribute 2 phases 2 strata in each phase
Type of analysis	Multivariate
Objective	confirmatory multivariate trend analysis
Analysis task	Look up desired pattern of transition - starbursts for each of the 4 SOP competencies
Cohort size (N)	45 students
What did iSAT explicate?	Visualised transitions of cohorts based on their intervention group to their success in the design task. Separately diagrams were visualized for each of the 4 SOP competencies. Highlighted more number of students were successful from the experimental group who did activities with rubrics than in control group which only got exposure to TELEDesc
iSAT Analytics affordance used	Highlighting descriptive model of transition for establishing effectiveness of intervention

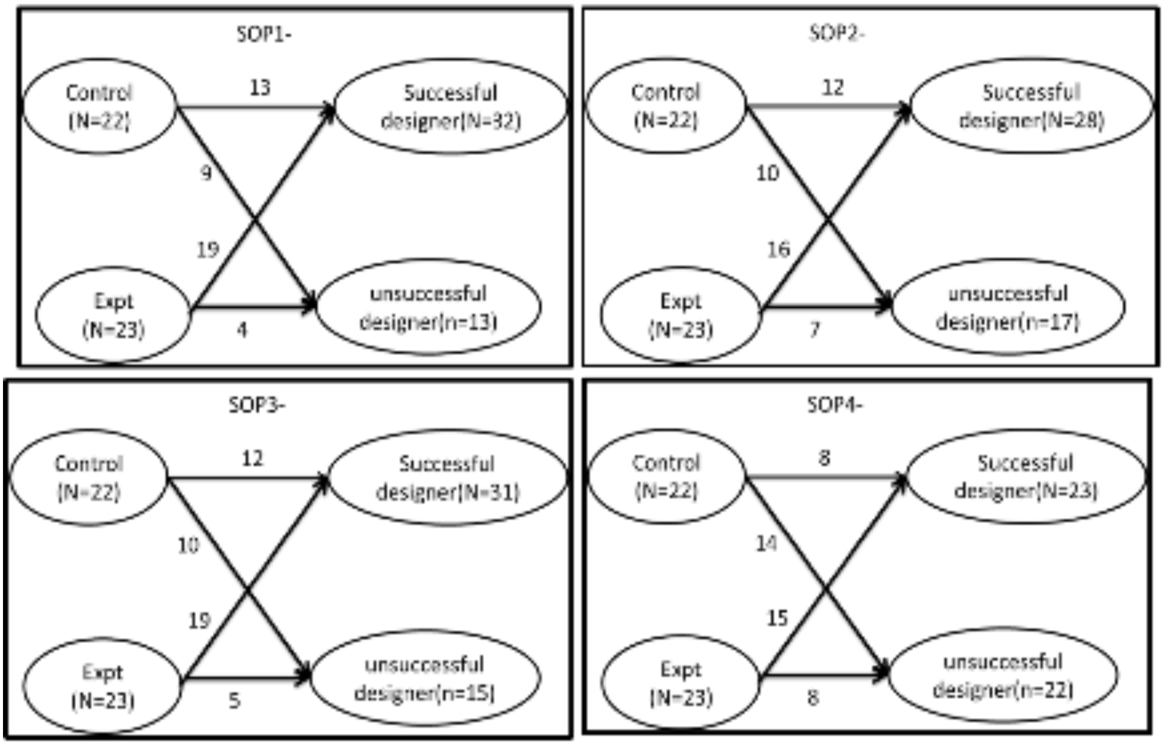


Figure 9-10 SAT diagram for successful and unsuccessful in SOP competency

Looking at the transition pattern the researcher could highlighted two information to compare. One was the relative proportion of transition between the two groups in the experiment for each SOP sub competencies. The other information was to compare the proportions of success / unsuccessful designers migrating from different groups across the SOP sub competencies.

The researcher found that "for the sub-competencies of 'identify specifications in open problem' (SOP1), 'use specifications to structure problem' (SOP 2) and sequence steps of design process (SOP3), more number of students fall in successful designer category in both groups. Careful observation showed that more number of students from experimental group (for SOP1 19/23) contributed to successful designer category than control group students (for SOP1 13/22). Further for the sub-competency of 'write structured problem statement' (SOP4), we found that more number of students from control group (only TELE-EDesC) lie in unsuccessful category (14) than successful category (8). But in the experimental group (TELE-EDesC + Rubrics) more students (15) fall in successful category compared to unsuccessful (08). We can infer that SOP4 is successfully attained by TELE-EDesC with rubrics group."

9.3.5 Scenario 5: Analysing trends in thinking skill development over time in a semester long course

This research focused on design, implementation and evaluation of an Automobile Project Implementation Template (APIT) for project based learning (PBL) approach in undergraduate engineering education. This instructional design template APIT, was implemented in a semester long undergraduate project. The project dealt with the design and manufacture of an automobile. The team of researchers included the instructor of that project too. In the template researchers designed evaluation activities aligned to the Bloom's level as shown in table 9.12.

Table 9-12 Assessments corresponding to Blooms level

Blooms level	Evaluation Technique
Create	Product demonstration
Evaluate	Oral Presentation and Simulation report
Analyse	Design report and CAD models
Apply	Hand sketches calculations, CAD drawing
Understand	Oral presentations and report
Recall	Multiple Choice Question

Based on these activities, one of the research questions was
What is the impact of Project Based Learning on student's higher order thinking skills (HOTS) and lower order thinking skills (LOTS)?

To answer this, the researchers set criteria to stratify the scores into three levels - low, medium and high, as described in research methodology and obtained transitions diagrams for LOTS and HOTS. They discuss three transitions within the (i) Lower Order Thinking Skills (Recall – Understand - Apply) (fig. 9.11) (ii) Higher Order Thinking Skills (Analyze – Evaluate - Create) (fig 9.12) (iii) and from Lower to Higher Order Thinking Skills (fog 9.13). The details of the iSAT analysis is provided in Table 9.13.

Table 9-13 Details of the study on trends of thinking skill development in PBL

Scenario 5	Analysing trends in thinking skill development over time in a semester long course		
Context	Reflection of f2f Classroom		
Study 8	Effect of intervention on SOP competencies		
Reference	Mistry R., Halkude S. & Awasekar D. (2016) APIT: Evidences of Aligning PjBL with Various Instructional Strategies for Enhancing Knowledge in Automobile Engineering. In Proceedings of the IEEE International Conference on Learning and Teaching in Computing and Engineering (LaTiCE, 2016).		
Research Questions	What is the impact of Project Based Learning on student's higher order thinking skills and lower order thinking skills?		
Important of question in that context	to test the effect of prior knowledge on attainment of SOP competency for different strata of students		
RQ type	consequence		
iSAT #	No 18 - transitions between level in LOTS	No 19 - transitions between level in HOTS	No 20 - transitions between level in LOTS to HOTS
Attribute	Achievement score		
Phases & Strata	*Higher order thinking skill | Lower order thinking skill* *High, Medium, Low"*		
# of attributes # of Phase # of Strata	2 Attribute 2 phases 2 strata in each phase		
Type of analysis	Multivariate		
Objective	confirmatory multivariate trend analysis		
Analysis task	Look up desired pattern of transition - starbursts for each 3 of thinking skills groups		
Cohort size (N)	25 students		
What did iSAT explicate?	Visualized transitions in performance of learners across tasks associated with Lower Order Thinking Skills (LOTS) and Higher Order Thinking Skills (HOTS). 25% students were able to starburst from medium level performance to high level across the LOTs to HOTs activities.		
iSAT Analytics affordance used	Descriptive modelling		

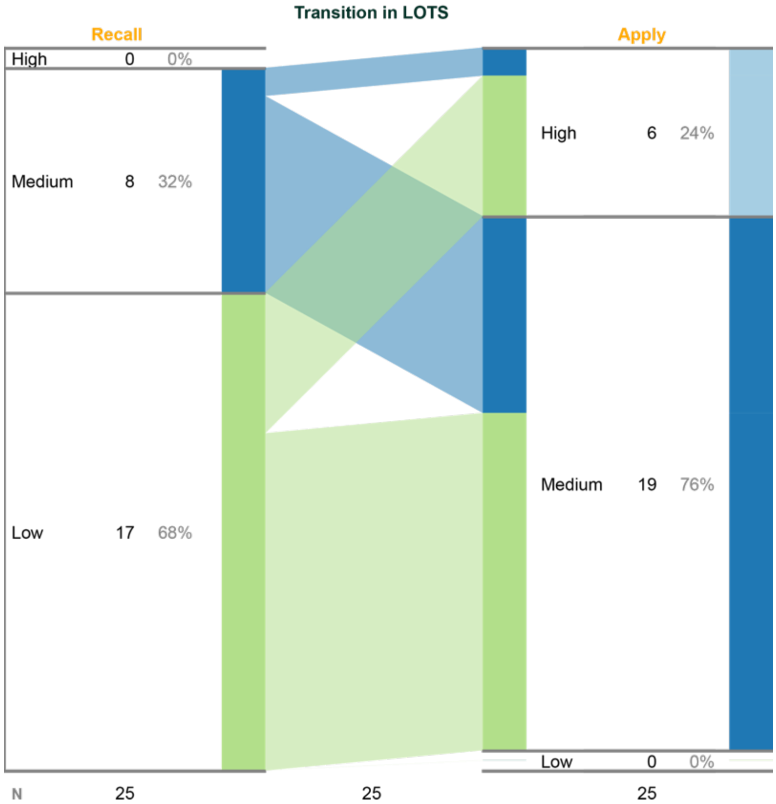


Figure 9-11 Transition pattern of performance between levels in Lower Order Thinking Skills

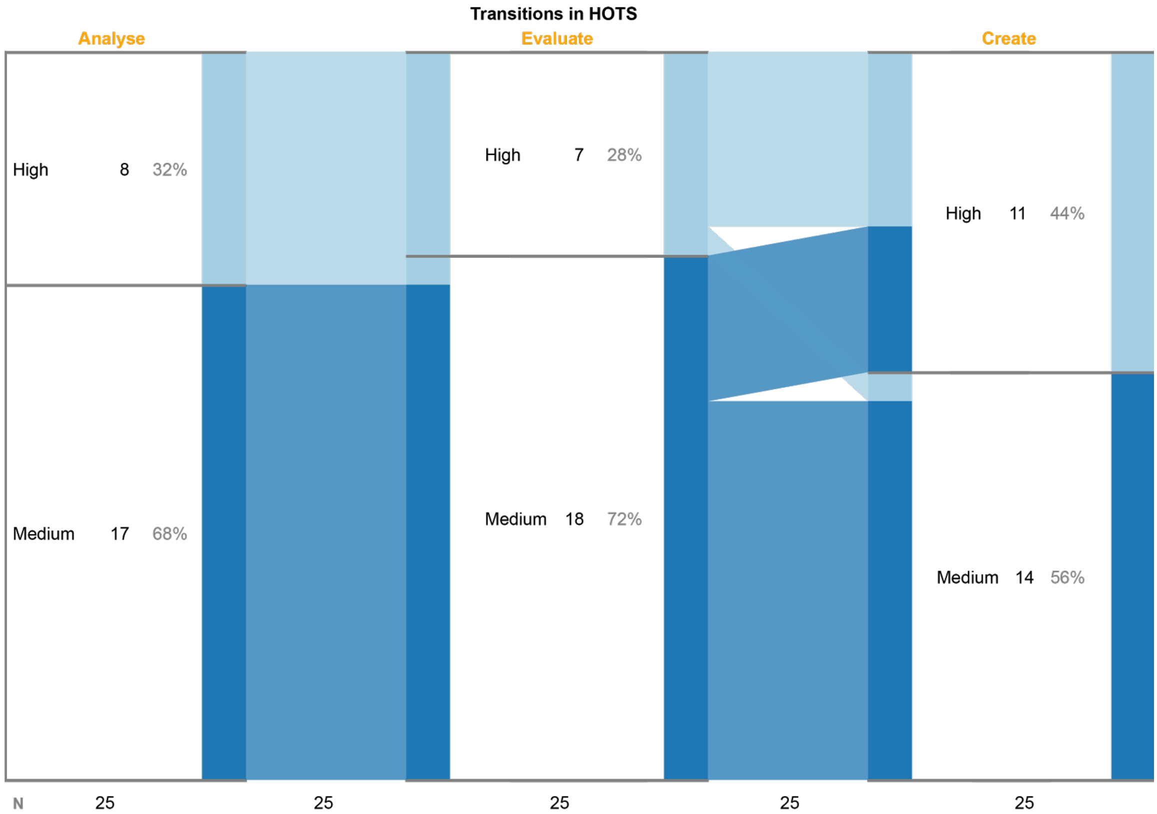


Figure 9-12 Transition pattern of performance between levels in Higher Order Thinking Skills

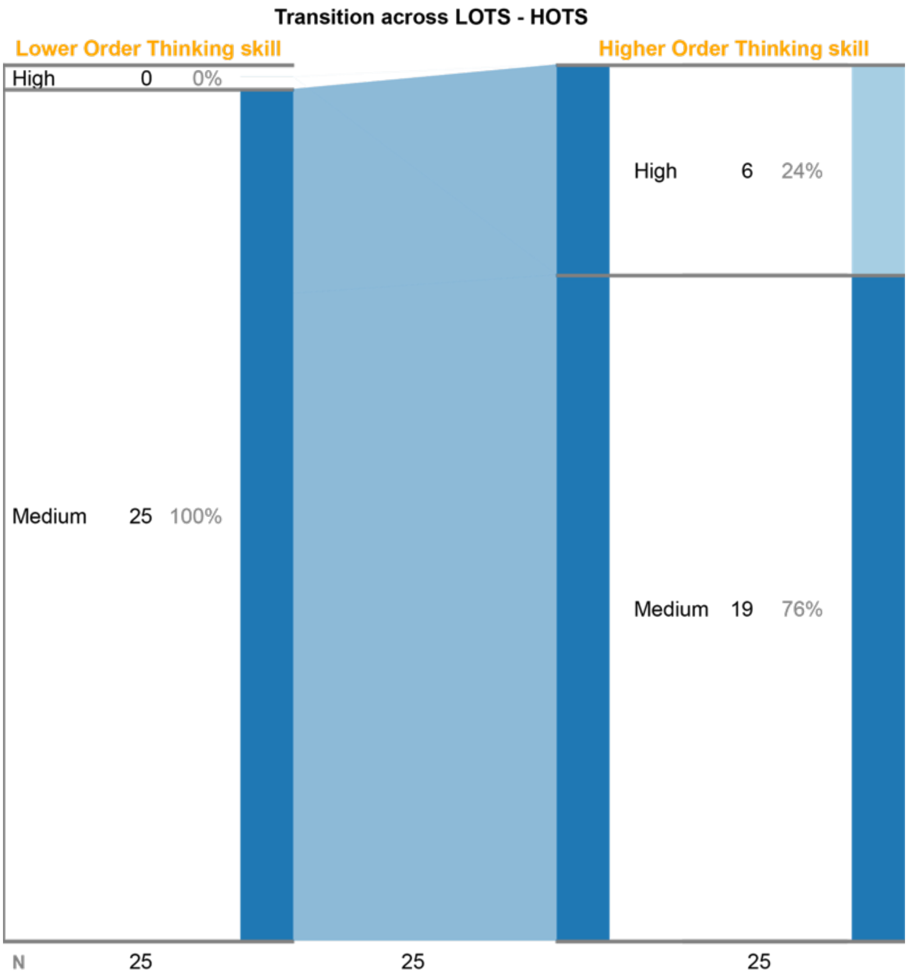


Figure 9-13 Transition pattern of performance between LOTS and HOTS

9.3.6 Scenario 6: Analysing performances of early learners in a battery of phonological assessments

This research investigated the effectiveness of using computer-assisted intervention for training early reading skills on kindergarteners. To become a proficient language user in alphabetical language such as English, reading instruction has emphasized the letter-sound correspondences. This is known as the phonological processing skill. Hence, most of the previous studies have highlighted the correlation between phonological processing skill and literacy development. While previous studies provided evidence of using computer-assisted intervention to improve phonological processing skill on children with special learning needs, few studies were conducted in Asia. This study was situated in Hong Kong where English is the second language in school and sought to extend current literature by examine such intervention on children without learning difficulties. I was a fellow researcher and analysed the data with the iSAT tool. A battery of tests related to phonological processing skills were conducted on kindergarten kids in the Hong Kong school and then the anonymous data was analysed by me. The patterns which emerged were then interpreted by the language learning researcher. In this paper we focused on results on two of the tests, Alliteration test and Rhyme test, out of the battery of 10 tests. Both these tests evaluate the phoneme detection by the students.

To understand the effect of computer aided instruction (CAI) on children's phonological processing skill, specific research questions which used iSAT are as follows –

1. *How does the performance vary across testing period for the two groups of intervention?*
2. *What is the relationship of performance between the Alliteration and Rhyme tests during each testing period?*

To answer this, we analyzed 10 SAT diagrams: 4 for temporal analysis - 2 groups x 2 categories of test and 6 for multivariate analysis - 2 groups x 3 periods of test. Table 9.13 gives the details of the iSAT analysis.

Table 9-14 Details of the study on performance trends of early learners' phonological skills

Scenario 6	Analysing performances of early learners in a battery of phonological assessments	
Context	Experiments in f2f Classroom	
Study 9	Studying relationship in performance across test items and across time	
Reference	Law M.C., Majumdar R. and Hew H.F. (2016) "Tracing Phonological Processing Skill in Early Childhood Through iSAT" in Proc IEEE 8th Intnl. Conf. on Technology for Education (T4E), 2-5 Dec. 2016.	
Research Questions	How does the performance vary across testing period for the two groups of intervention?	What is the relationship of performance between the Alliteration and Rhyme tests during each testing period?
Important of question in that context	Tracing the temporal change would help to identify proportions of the students with specific patterns across pre, post and retention test.	The analysis would highlight the relationship of performance in the two tests for that particular group of participants.
RQ type	Disproportion	Relation
iSAT #	No 21 - No 24 transitions across different assessments	No 25 - No 30 transitions between Alliteration and Rhyme test
Attribute	Standardized achievement score	
Phases & Strata	*Pre-Test score | Post-Test score |Retention Test score* *Well Above Average, Above Average, Average, Below Average, Well Below Average*	Alliteration (AT)|Rhyme (RT) Test WAA, AA, A, BA, WBA
# of attributes # of Phase # of Strata	1 Attribute 3 phases 4 strata in each phase	1 Attribute 2 phases 4 strata in each phase
Type of analysis	Temporal	Multivariate
Objective	confirmatory temporal trend analysis	confirmatory multivariate trend analysis
Analysis task	Compare 2 transition map	
Cohort size (N)	15 students in Computer assisted Instruction group 15 students in pencil-and-paper training group	
What did iSAT explicate?	Traced performance variation across three testing periods for different assessment tests. Computer aided instruction helped to improve posttest performance and maintain it across retention test more than the paper-based instruction.	Helped to analyze performance patterns between the two test categories (AT and RT). For example, in the posttest period, CAI cohort showed similar desired performance levels between AT and RT. Whereas in the paper based instruction group there were performance switches.
iSAT Analytics affordance used	Descriptive modelling	
Implications	The trend analysis indicated the effectiveness of the computer aided instruction for phoneme identification by early learners. This helped to conceptualize further possible studies to investigate the relationship with phoneme identification and production in terms of cohort dynamics.	

The temporal analysis (see fig 9.14) highlights, both pencil-paper approach and CAI approach helps children to gain phonological processing skills. But iSAT further highlights that in the CAI group (experimental group), there are cohorts which perform higher than the Average level while paper-based group (control group) restricts to only Average levels. In the Post-test learners who perform Average mostly remain at that level in the Retention test for both the tests. Scores of students in the control group fall into a decline after 10 weeks while this phenomenon seems less likely to happen in the experimental group.

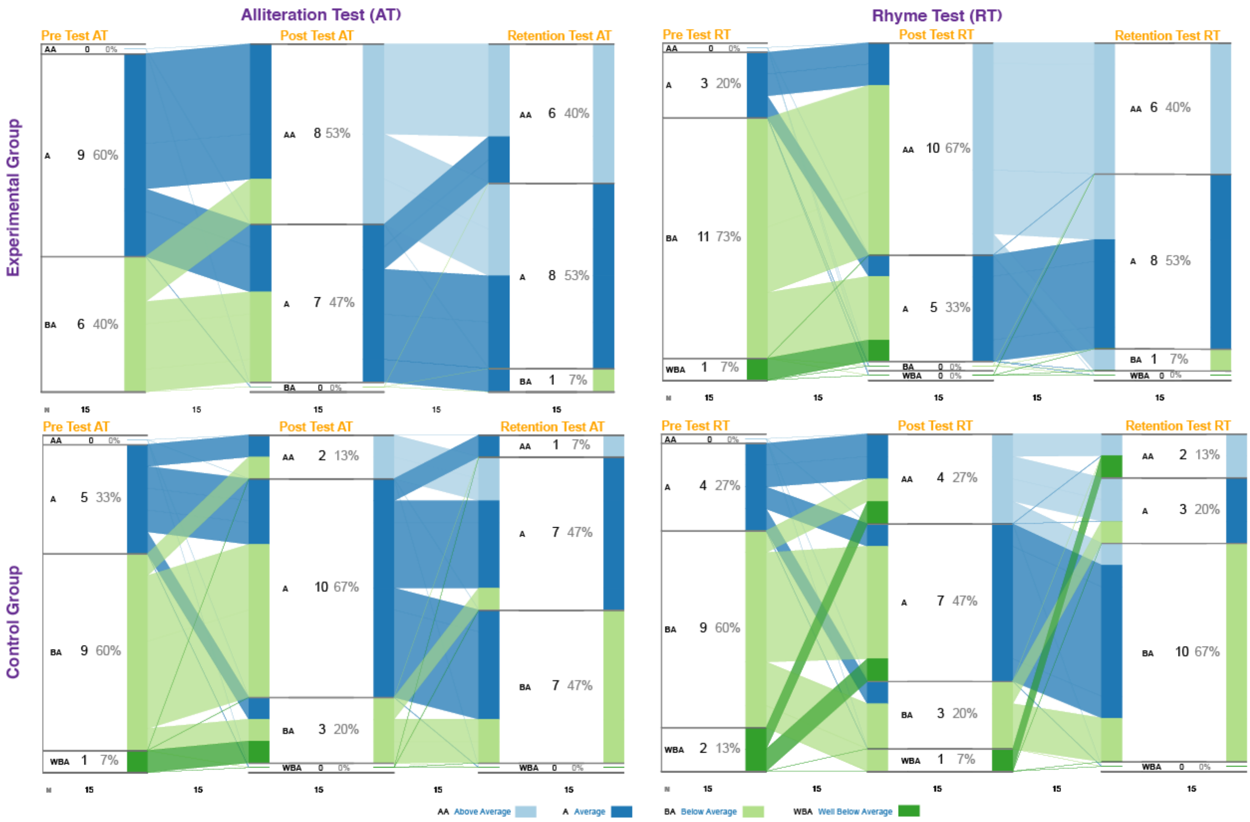


Figure 9-14 SAT diagram for temporal analysis

The multi attribute analysis (see fig 9.15) highlights performance in the Alliteration and Rhyme test is mostly aligned across the testing period. Though initially nearly half of the learners did better in Alliteration than in Rhyme, but after intervention that population reduced, and during Retention period it was 1 in every 4 learners on an average. Only 1 out of 5 learners perform better in Rhyme test than Alliteration test across all period. It is seen that though there is no alignment in the pre-test condition, but after CAI intervention more than half of the learners perform average or above average across both Alliteration and Rhyme test during posttest and retention test period. There are cohorts of learners who have below average performance in both the tests during pretest period, but that pattern doesn't remain in the post phase. After 10 weeks, only the paper based activity group has nearly half of their learners perform below average in both the tests.

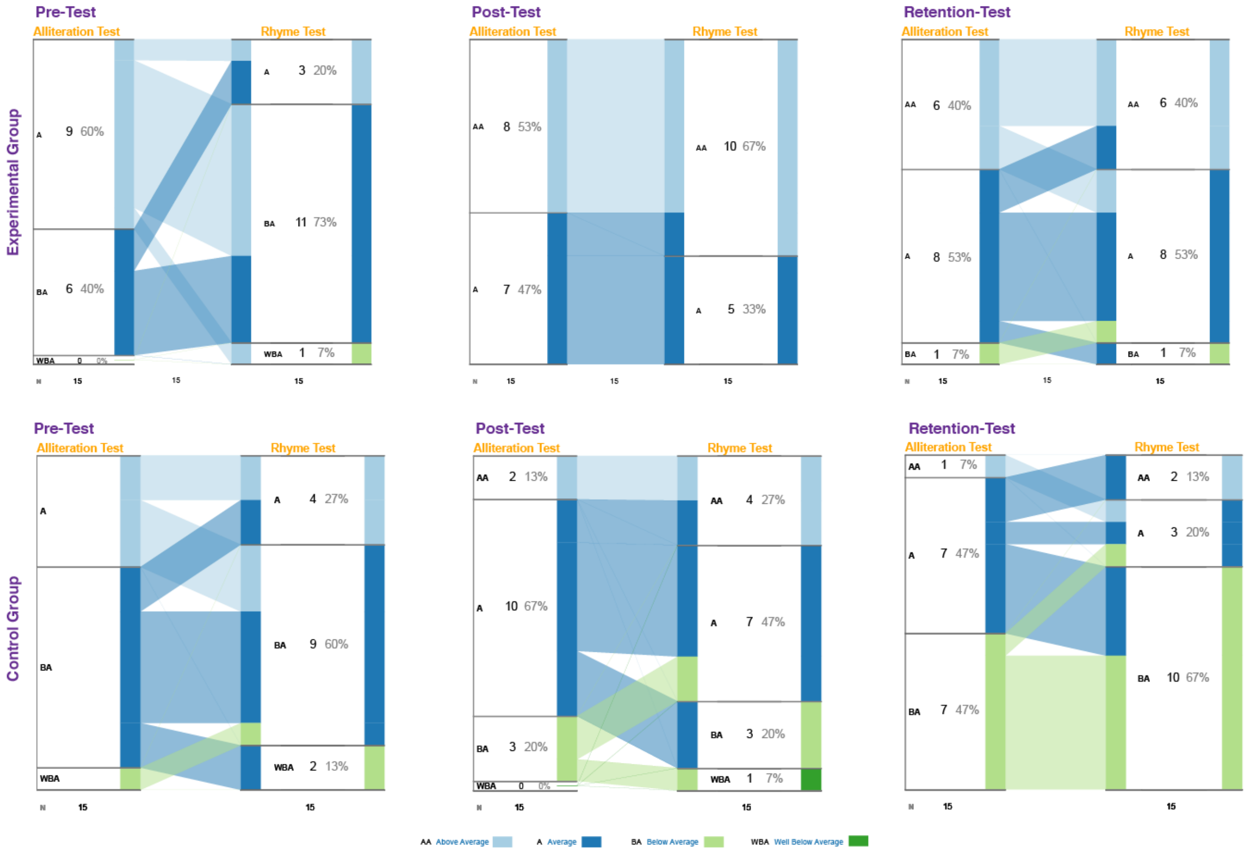


Figure 9-15 SAT diagram for multivariate analysis

The reported paper was the first attempt to analyze patterns of the performance of phonological processing skill with the help of iSAT. Considering Alliteration and Rhyme test, we illustrate this performance variation across the Pre-Post-Retention test and between them for CAI and pencil-paper based intervention.

The two main findings of the analysis were the following:

First, the results of the current study indicate that computer- assisted intervention seems to have positive impact on children without special language learning needs. It seems to be consistent with previous clinical studies in Western countries. Since participants were selected from the population of a local kindergarten in Hong Kong, we could say that the positive effect of CAI remain positive across region.

Secondly, the results indicate that the positive effect of computer-assisted intervention does not only appear after the intervention, but also last for 10 weeks later until the retention stage. Therefore, the findings have demonstrated that integrating CAI into teaching strategy was beneficial to students as long-term effect.

9.3.7 Scenario 7: Analysing transitions of students' perceptions in surveys

In Chapter 6 we reported the research study that had evaluated the effectiveness of the LAMP framework. During this study we used the earlier version of iSAT. It assisted us to trace the perception of the students regarding the muddy point collection and addressal strategy applied in the large class. Table 9.15 presents the details of the analysis and we present the current version of iSAT representation for the same dataset in Figure 9.16.

Table 9-15 Details of the study to analyse transitions in students' perception

Scenario 7	Analysing students conceptual change during Peer instruction
Context	Reflection of f2f Classroom
Study 10	Studying effectiveness of implemented framework
Reference	Majumdar, R., & Iyer, S. (2013, December). LAMP: A framework for large-scale addressing of muddy points. In Technology for Education (T4E), 2013 IEEE Fifth International Conference on (pp. 127-132).
Research Questions	How effective is the LAMP framework? -For collection of muddy point from the students -To address the muddy points of the students
Important of question in that context	to test the effect of prior knowledge on attainment of SOP competency for different strata of students
RQ type	Conjunction
iSAT #	No. 31: Transition pattern of students perception across survey items
Attribute	Perception scores
Phases & Strata	*Question Posed | Answered Received* *Agree, Neutral, Disagree*
# of attributes # of Phase # of Strata	1 Attribute 2 phases 3 strata in each phase
Type of analysis	Multivariate
Objective	exploratory multivariate trend analysis
Analysis task	Look up transitions from full transition map
Cohort size (N)	274 students
What did iSAT explicate?	The visualization of the survey response helped to answer both the RQs together and also highlighted the transitions between the two survey items The perception trend indicated the proportion of the group whose preference patterns could be further investigated.
iSAT Analytics affordance used	taking research decision based on comparing descriptive pattern

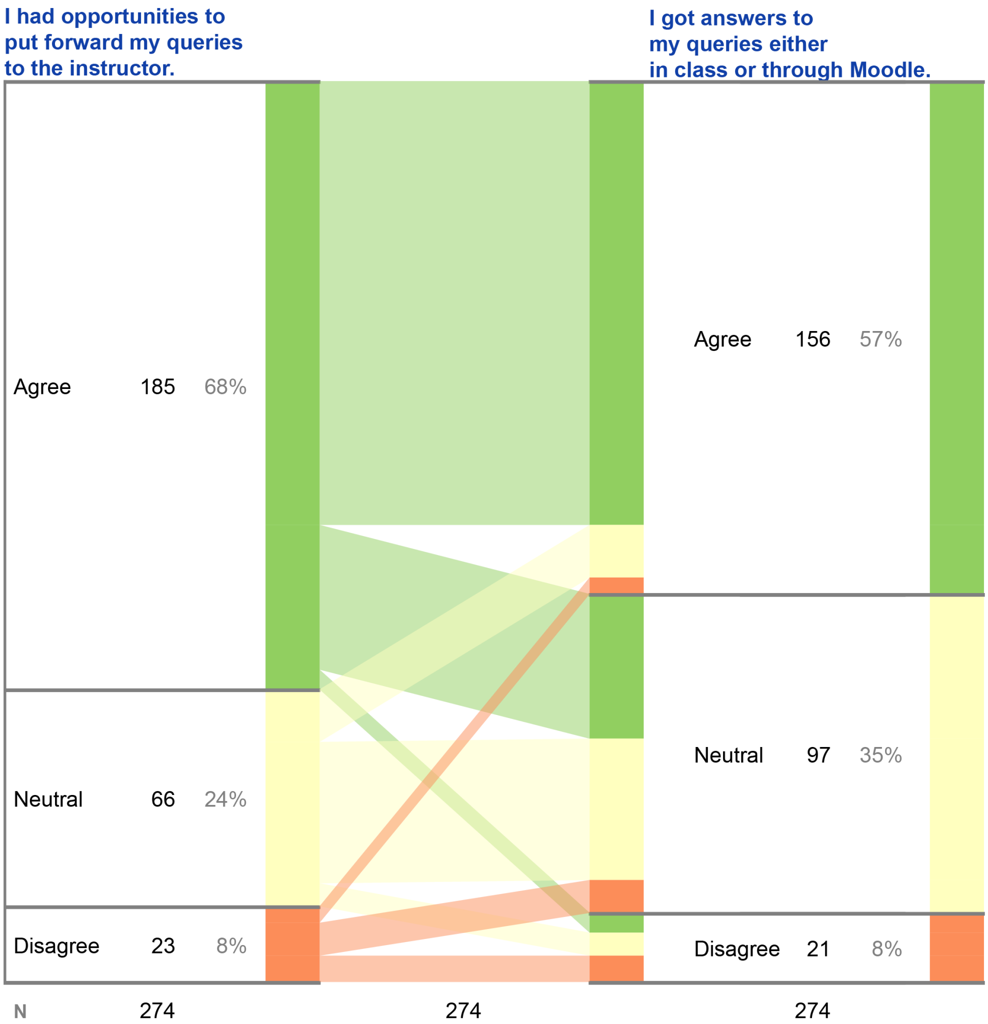


Figure 9-16 Transition of students' perception over the survey questions

9.3.8 Scenario 8: Assessing learning gains in online workshops.

This project focused on the implementation and evaluation of a large-scale, distance mode, training workshop in Research Methods in Educational Technology (ET), for in-service engineering college teachers in India. The goal of the workshop was to prepare teachers to conduct action research in their courses. As a part of the training, the participants were exposed to the evaluation criteria that are expected in a research paper - Novelty, Positioning, Soundness of Procedure and Evidence (Smith 1990), and explained how researchers need to pay attention to these criteria during the process of planning and conducting research.

A total of 3896 teachers participated in the workshop, with 1141 (29%) participants completing at least 50% of the assignments. To evaluate the effectiveness of the implementation, the researchers conducted a study with pre-post research design. They designed assignments based on an Idea Planning Template (IPT) and a Study Planning Template (SPT) which was considered as the pre-test and post-test respectively. These assignments were graded based on a rubric which had four dimensions of evaluation, corresponding to the criteria of Novelty, Positioning, Soundness of procedure and Evidence. Each dimension was evaluated on a 4-point scale: Very Low, Low, Medium and High, each of which had detailed descriptors relevant to the dimension being evaluated.

The specific research question was *What was the improvement in the participant's knowledge of ET research methods, both measured and perceived?*

The iSAT model assisted in answering what is the pattern of improvement of the participants who had submitted both the idea planning and the study planning assignments. The Phases were the IPT score and the SPT score of the participants. Strata represented the levels based on different rubric values. This provided a zoomed in view of which group based on the rubric score had what proportion of transitions while moving from the idea stage to the study planning stage. The researchers could analyse separate transition maps for each of the four dimensions. The proportion of upward transitions indicated the effectiveness of the implementation of the workshop. Additionally, this mapping also assisted the instructors of the workshop to decide what proportion of the online participants would be selected for the mentoring program which followed. Table 9.16 provides the details of the iSAT based analysis

Table 9-16 Details of the study to analyse learning gains in online workshop

Scenario 8	Assessing learning gains in online workshops.
Context	Reflection of online Classroom
Study 11	Studying improvement in each aspect of evaluation
Reference	Warriem J. M., Murthy S. and Iyer S. (2013)Training in-service teachers to do action research in educational technology. in Proc. IEEE 5th Intnl. Conf. on Technology for Education (T4E), pp.192-199, 18-20 Dec. 2013.
Research Questions	What is the improvement in participants' ET research methods knowledge as a result of the workshop?
Important of question in that context	The analysis would help to get an overview of performance of workshop participants in terms of their achieved rubric score.
RQ type	Consequence
iSAT #	Transitions across rubric score during ideation to study planning stage for different items No 32 - for novelty, No 33 - for positioning, No 34 - for soundness, No 35 - for evidence
Attribute	Achievement score
Phases & Strata	*Idea-planning| Study-planning* *High, Medium, Low, Very low*
# of attributes **# of Phase** **# of Strata**	2 Attribute 2 phases 2 strata in each phase
Type of analysis	Multivariate
Objective	exploratory multivariate trend analysis
Analysis task	Look up transitions from full transition map
Cohort size (N)	242 participants
What did iSAT explicate?	Visualized improvement in mentee's performance across the online mentorship program. Also helped to identify cohort, which can be trained further in face-to-face mode.
iSAT Analytics affordance used	taking instructional decision based on comparing descriptive pattern
Implications	Based on the descriptive model the researcher could define the criteria for selection for the face to face workshop and further allocate resources for that particular number of participants

The rendered iSAT visualisation for the novelty dimensions is presented in Figure 9.17.

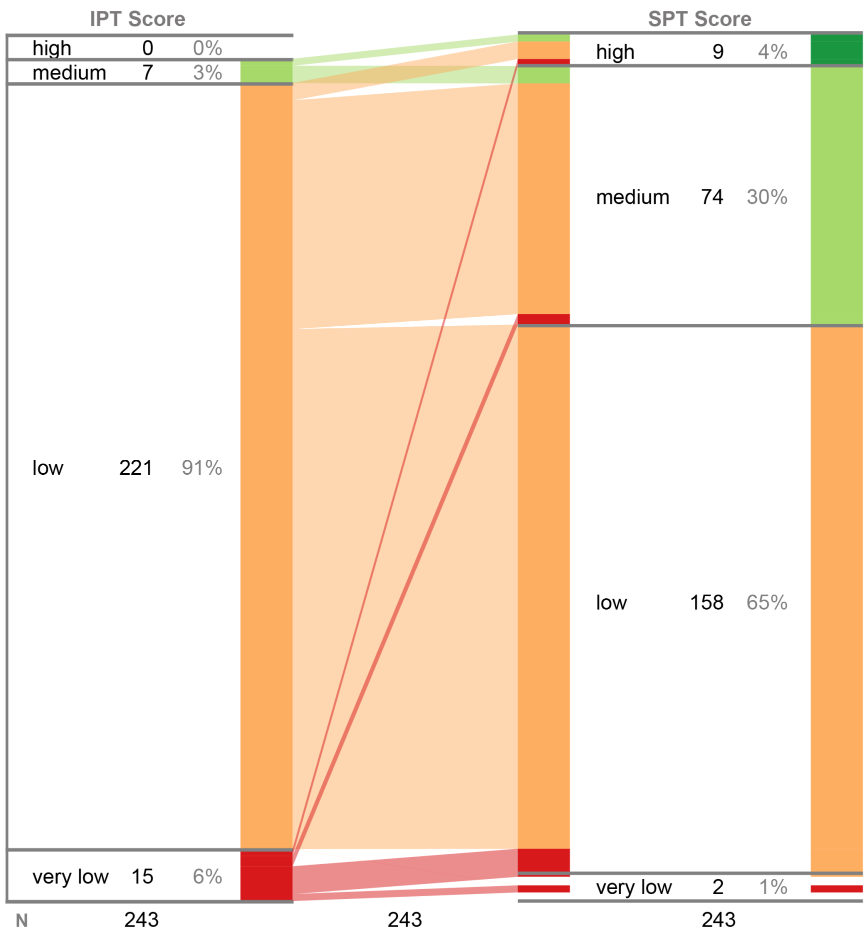


Figure 9-17 State transition from IPT to SPT for novelty dimension

9.3.9 Scenario 9: Analysing frustration in an intelligent tutoring system (ITS)

An intelligent tutoring system is a computer-based self-learning system which provides personalized learning content to students based on their needs and preferences. In this research, the researcher developed an approach that detected and responded to students’ frustration. This system was implemented in MindSparks, a mathematics ITS with large scale deployment. To evaluate, the number of frustration instances per session after implementing the approach were analyzed. The researcher found the number of learner’s frustration instances significantly decreased while working in MindSpark sessions.

The researchers further investigated the research question, *What is the impact of the motivational messages on students’ frustration, learning achievement and time spent to answer the question?*

To analyse, data was collected from different schools. Learner log captured the different learning achievement and response time of the students to answer.

To initially analyse the multiple attributes of the students’ frustration instance collected Though this particular data set was not published in any forum, application has relevant usefulness. The researcher had initially used an earlier version of the SAT visualization and felt the proportion information was not highlighted. So in his thesis only the contingency table was reported. Similar analysis is possible by just visualising the data through iSAT and analysing Starbursts and Slide patterns. The initial visualised form and the iSAT representation of the dataset is presented in Figure 9.18 and 9.19 respectively.

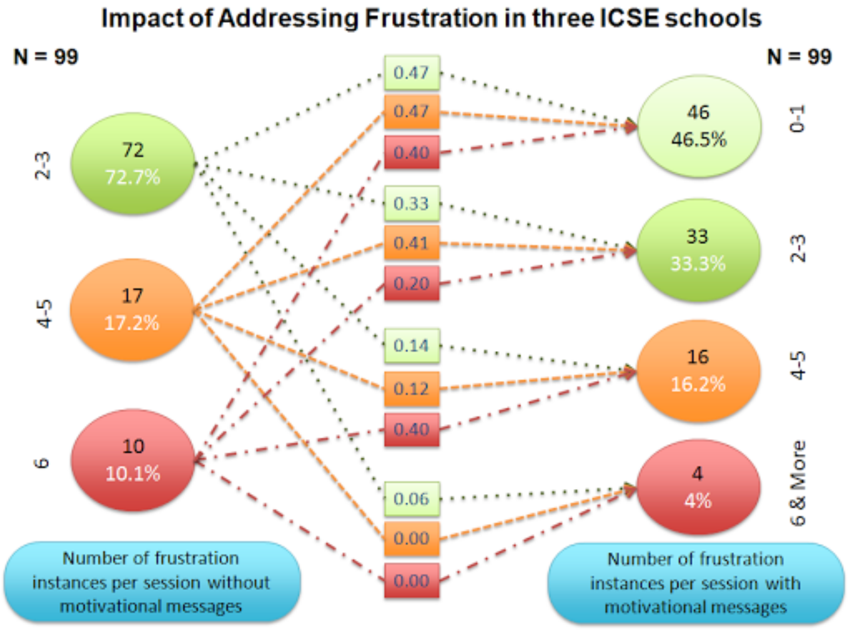


Figure 9-18 State Transition Diagram to track number of frustration instances of students

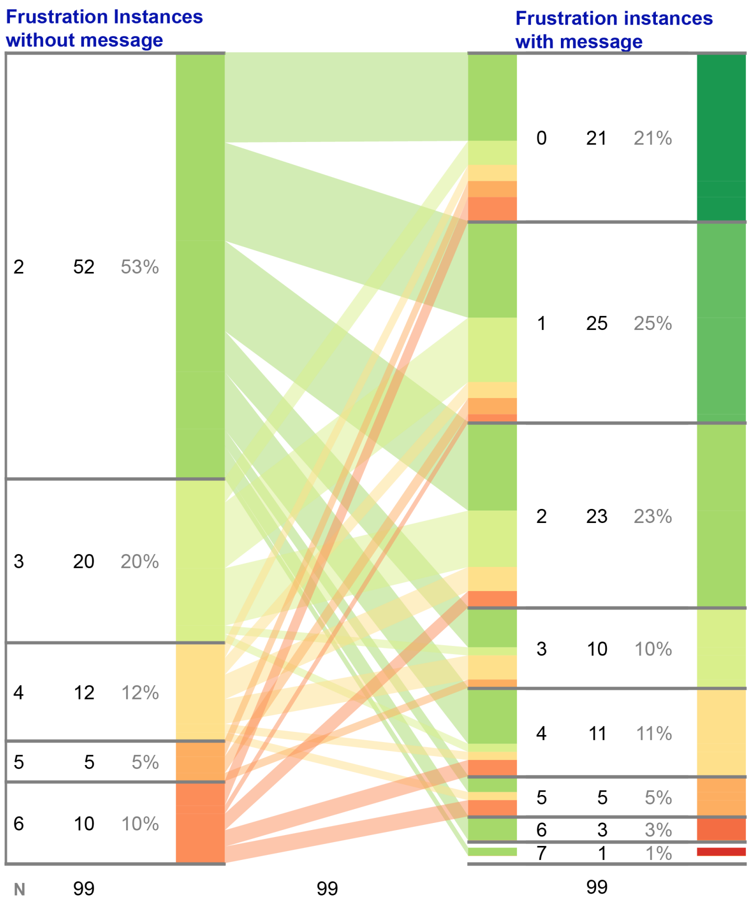


Figure 9-19 Re-rendered iSAT visualisation of the dataset

Table 9-17 Details of the analysis of students frustration in ITS

Scenario 9	Analysing frustration in an intelligent tutoring system (ITS)
Context	Experiments in ITS environment
Study 11	Impact of motivational message in ITS
Reference	Rajendran R. (2014) Enriching Student Model in an Intelligent Tutoring System. Thesis
Research Questions	What is the impact of the motivational messages on students' frustration, learning achievement and time spent to answer the question?
Important of question in that context	The effectiveness of design of the motivational message can be investigated in further details by answering this question. Its effect, can be studied from the perspective of learning achievements and time spent on answer for different cohorts of students
RQ type	consequence
iSAT #	No 36: Transitions of frustration instances before and after showing motivational messages in an ITS session
Attribute	Frustration Instances per session
Phases & Strata	*Without motivational message| With motivational message* *0-1, 2-3, 4-5, 6 and above*
# of attributes **# of Phase** **# of Strata**	1 Attribute 2 phases 4 strata in each phase
Type of analysis	Temporal
Objective	Exploratory multivariate trend analysis
Analysis task	Compare transitions within full transition map
Cohort size (N)	99 learners from 3 schools
What did iSAT explicate?	Represent trends of frustration instances of learner across activities in an intelligent tutoring system. It highlighted there was a decrease in frustration instances when the activity had motivational messages than one without.
iSAT Analytics affordance used	Descriptive modelling
Implications	The initial analysis of tracing transitions of frustration instances prompted the researcher to zoom into a specific cohorts with respect to their learning achievements and time spent on the session.

9.4 Discussions regarding Usefulness and Utility of iSAT

Both instructors and researchers were users of iSAT. iSAT assisted users to generate a descriptive model of their contexts in terms of its transition patterns across attributes and visualize by iSAT diagram. This highlights the cohort dynamics of the specific user context. The phases can either represent temporal information or can represent stratified data of different attributes (categories). The retrieved information can then be interpreted for specific understanding of the context. Table 9.18 describes the level of visual analysis tasks possible during stratified attribute tracking, in terms of its constructs.

Table 9-18 Visual analysis task and what it informs

Levels of Visual Analysis task	What it indicates of cohort dynamics	
	Across categories	Across periods
Identify characteristics of Phase	Trace the most prominent level of performance, Trace if absence of any performance level	
Identify characteristics of transitions	Trace proportion of desirable performance transitions across intervention	Trace proportion of transitions across performance levels in consecutive test periods
Identify Patterns in Transitions	Trace Alignment and Returns of performance across phases	Trace proportion of desirable vs undesirable sets of transitions. Analyze performances switches and alignments
Compare two SAT diagrams	Indicate similarities and differences of trends in patterns of two performance transitions having same phases.	

Dyckhoff et.al (2013) discuss about the goals of Learning Analytics. iSAT can also assist the researcher to achieve many of those goals by providing a model and an external representation. It can track user activities (scenario 1, 3, 9), capture the interaction of students with resources / the interactions among students (scenario 7, 8), provide an overview (scenario 1, 2, 3,5), highlight important aspects of data (scenario 4,6,7,8), provide different perspectives (scenario 1,2,3), draw the user’s attention to interesting correlations and provide decision support (scenario 2,7,8).

Context of iSAT usage and their primary users: In the set of use cases that we analysed, usage of iSAT model was primarily in two contexts. The first context of use was in online or face to face classroom teaching. We found two sets of primary users in this context. Instructors were the primary users where they evaluated collected data at the end of the course. In some other cases the data was analysed either by the instructor themselves to reflect on their practices or by researchers studying activities in their classroom. The second context was ET research studies with researchers as the primary user of iSAT.

Assistance that iSAT provided: Primarily iSAT was helpful to develop a descriptive model in terms of transitions across data attributes and present it visually. Some of the studies used the descriptive model to take further decisions in their context.

Table 9-19 Distribution of studies which used iSAT

Scenarios		Context of use		
		Face-to-face classroom / Online course		**ET research studies**
iSAT assisted in	**descriptive modelling**	Understanding student dynamics in project based learning	Studies related to TPS activities in a large enrolment lecture	Analysing frustration in an intelligent tutoring system
			Analysing performances of early learners in a battery of phonological assessments	
	decision making	Assessing learning gains in online workshops	Analysing transitions of students perceptions in survey response	Studies to analyse students problem posing exercises
		Analysing students conceptual change during Peer instruction.		Analysing students engineering design competency of Structuring Open Problem
	Primary user	**Instructors**	**Reflective Practitioners / Researchers in classroom**	**Researchers**

9.4.1 Descriptive modelling of teaching learning in online or face to face classroom / course.

Two instructors in a private engineering college in western India implemented a project based learning (PBL) activity for a semester long elective course. They also devised intermediate learning assessments which were mapped to different levels of the revised Bloom's' taxonomy (Anderson, et.al. 2001). iSAT provided for them a means to trace performance dynamics across that period of time, as the students were assessed in progressively higher order thinking. *It highlighted 24% of students participating in the PBL in that cohort improved performance across lower order and higher order thinking skills and rest 76% remained in the desired levels.*

The CS101 course at IIT Bombay is a large attendance class with nearly 450 students. During one offering, the instructor implemented the Think-Pair-Share (TPS) active learning strategy in the large lecture class. The first study, which also initiated the meso-level analysis perspective, studied the engagement pattern of the students during an active learning session. The initial conjecture was most learners don't concentrate during the individual thinking activity and directly piggyback on the peers during the pairing and discussion phase. *But the engagement dynamics helped to indicate the contrary that significant proportions of the cohorts were engaged across the phases as observed by their on-task behaviors.*

The researchers investigated the effect on learning due to the active learning. A quasi experimental two group study was designed. Analysis of the performance data at a macro level indicated statistical differences of two groups, one which had TPS and another which was taught with an animation. The meso-level analysis gave the transition patterns of performance for the two groups. *iSAT highlighted higher proportions of students improved by active learning than watching interactive animations.*

A study on early learners phonological processing skills gave different intervention to school children in Hong Kong to learn English as their foreign language. Both the groups were then assessed across time on different phoneme detection and phoneme production tests. iSAT could help trace the transition patterns across time for each test and across the different tests at a given time. The study compared the Computer Aided Instruction (CAI) group and the Printed Format Instruction (PFI) group with respect to their transitions in levels of performance on the different assessments. *iSAT highlighted the specific improvement pattern of the students in the CAI group compared to the PFI group in Alliteration and Rhyme test across repeated measures and between the two test at each time instance.*

9.4.2 Descriptive modelling in ET research studies.

Learners can get frustrated during a learning session while interacting with an Intelligent Tutoring System (ITS). One researcher was analysing the effect of motivational messages on the number of frustration instances that the learners exhibit. The meso-level view traced the transitions during the phase which had no frustration message versus the other which had specific messages. *iSAT provided a way to probe deeper into the data collected.*

9.4.3 Decision making in online or face to face classroom / course.

Peer instruction is an active learning strategy where the instructor poses a conceptual question with multiple choice answers. In the first phase, the learners vote the answer individually, in the next phase they argue with their peer regarding their choice of option and resolve any differences. Then they re-voted their choices. In an extended version, the learners are given a second different question on the same concept (isomorphic question). The meso-level analysis traces the transition of the voted options by the learners. *Based on the transition pattern, we have proposed instructional decisions that can be taken for the post-PI activities.*

Often instructors collect survey-based user feedback. A CS101 instructor also collected survey-based perception of students regarding their ease of asking questions and receiving their answers. The instructor had designed a large scale addressal mechanism of students doubts (muddy points questions). A study was conducted to investigate what was the preferred mode of muddy point addressal for the students. In the survey there were separate questions to assess whether the students could pose their queries and whether they were got answers to those queries. *The meso-level view assisted to visualise the proportion of the students who agreed to both the questions. This analysis was used to indicate which group's favoured mode of questioning to be further analysed.*

An instructor of a teacher professional development program utilised iSAT to analyse the transitions in performance across assessment items. *The transition pattern was used to evaluate the effectiveness of the program and further select the cohort for advanced training.*

9.4.4 Decision making in ET research studies.

The study on students' problem posing exercise highlighted cohorts based on their pre and post-test performance and the difficulty of the problem statements that they posed on a given topic. *The transitions across the pre-test performance, the difficulty of the problem posed and the post-test performance traced the relationship between the performance and nature of questions posed. The researcher could then investigate qualitatively the reason of such a pattern.*

In another study, the researcher designed 4 different activities for Structuring Open Problems (SOP). The meso-level analysis enabled to view the transition pattern of students prior achievement to their SOP competencies. *The patterns of performance highlighted to the researcher that in 3 out of 4 sub competencies students across prior achievement levels were mostly successful. But one of the sub competencies, writing problem statements in structure manner, did not improve for that cohort.*

Among our analyzed use cases, iSAT helped user to compare classroom interventions and introduce variations in learning design (see Table 9.20). Some case studies used the transition patterns to take further instructional or research decisions.

Table 9-20 Example of case studies where different groups were compared with iSAT

Study	Group 1	Group 2
Learning effect of active learning through TPS	TPS group	Interactive lecture group
EFL instruction for early learners	Computer based instruction	Paper based instruction
Effectiveness of Problem posing exercise	Novice group of learners	Advanced group of learners
Different learning design	Developing SOP competency with TELE-eDesc	Developing SOP competency with TELE-eDesc + Rubrics

Based on the 12 research studies that reported iSAT model to analyze their research data, 4 utility of iSAT emerges as follows:

- To build descriptive model of any teaching-learning scenario based on transition dynamics.
- To compare different scenarios of teaching-learning based on transition dynamics.

- To refine or explore new research questions in ET research contexts.
- To update instructional strategies or decisions in any teaching learning context.

A descriptive model of the utility of iSAT is presented in the Figure 9.20.

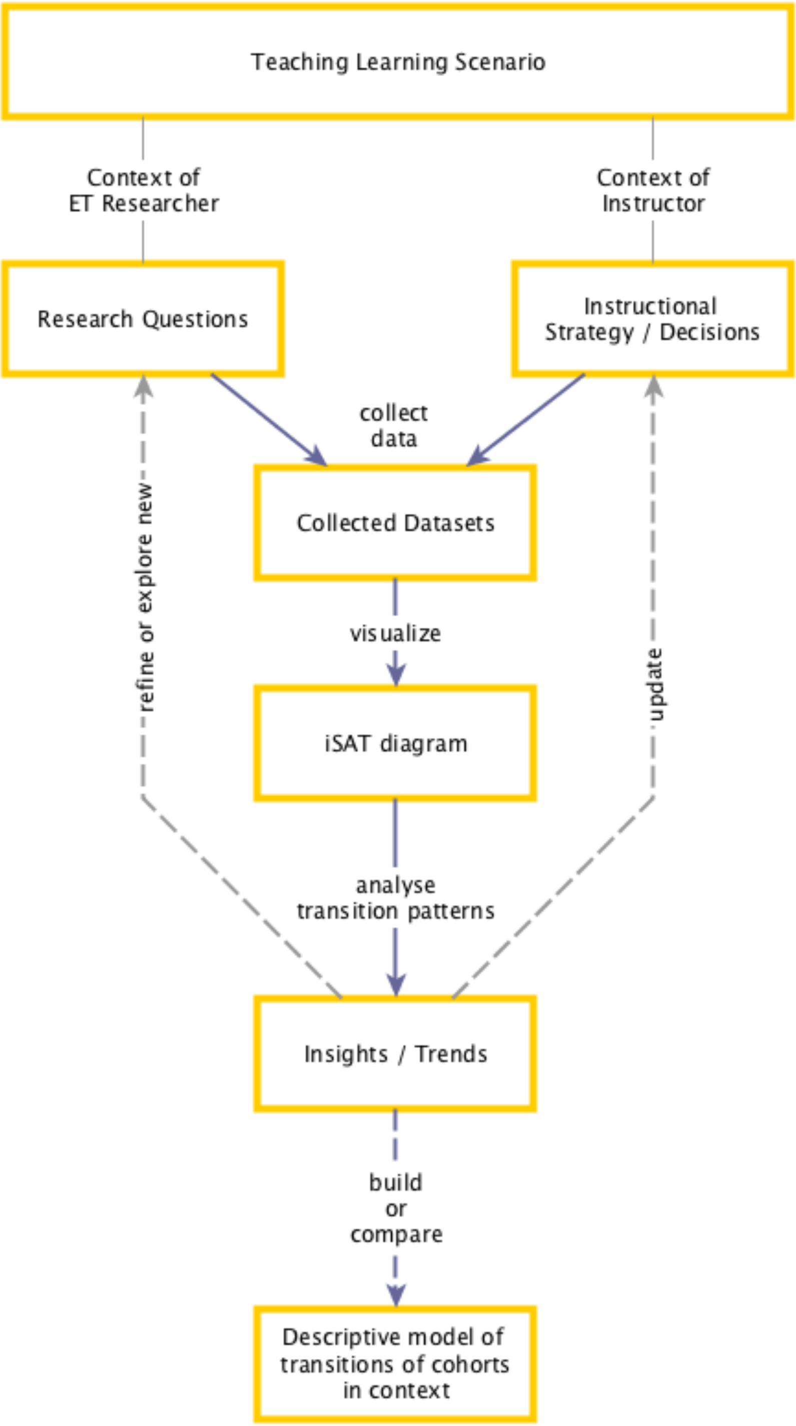


Figure 9-20 Descriptive model of utility of iSAT in research and teaching learning context

It is interesting to note the different scenarios of teaching learning and the type of data that could be analysed with iSAT. It was used by researchers to analyse their ET research studies as well as by instructors to analyse classroom dynamics such as in a large-scale online professional development workshop. In these scenarios different types of collected learner attributes were analysed with iSAT, such as their performance, voted answers, observed engagement, perception, affective parameters and created artifacts. This wide range prompted us to investigate applicability of such a model of analysis.

9.5 Applicability of iSAT

We analyzed the research context, class of research questions and the type of collected data that can be analyzed with iSAT. To understand the research context, we referred to the Learning Analytics and Knowledge (LAK) conferences to define the context of analysis that the community is focusing on based on the session that they run. Based on that grouping we argue applicability of iSAT in those categories.

To understand categories of research questions we did a literature survey and found Dillon (1984) proposed a classification of research questions (RQs) in education and enterprises of inquiry by synthesizing different questioning schemes. We examined which kind of research questions can iSAT possibly assist to answer.

To indicate the data that can be parsed through iSAT model, we again focussed on the literature to find what the data types that are collected are in educational context. The applicability criteria were set based on those collected data.

To further get evidence of the above set of applicability parameters we looked at sample research studies which did not use iSAT and analysed applicability of the model for that specific context. Five studies were selected at random from the Transactions of Learning Technology journal and analysed for this purpose.

9.5.1 Research Context in which iSAT can be applied

To scope the context of research we analyzed the sessions of Learning Analytics and Knowledge (LAK) conferences (2011-2015) and broadly aggregated 10 research contexts. There are i. Theory and Methods, ii. Frameworks and Tool description, iii. Analysis of students' performance (identifying at-risk students and assisting reflection & awareness), iv. Analyzing students' behaviour, affect and engagement, v. Predictive modelling and application in recommender systems / tutoring system, vi. Process mining and analytics, vii. Discourse / Text analysis, viii. LMS data analysis (analysis of resource utilization), ix. MOOCs (analysis of demographics/ assessment results/ connections/discussion forums) and x. Others (Social & collaborative learning analytics, Multilevel & multimodal learning analytics).

iSAT can be used in the context of analyzing students' performance and affective parameters. Both these students' attributes can be studied in isolation or transitions across them can be traced by iSAT. In the context of MOOCs, iSAT can visualize cohorts of learners by their demographics and further trace transitions in attributes of those learners. In the context of studying resource utilization of LMS and MOOCs, iSAT can visualize levels of utilization and transitions with respect to other attributes of students. Such multivariate data can be collected in different contexts like, online courses, designed teaching-learning classroom interventions, or pseudo-experiments in lab settings.

9.5.2 Category of Research Questions which can be investigated with iSAT

Table I in (Dillon, 1984) presents various categories of questions that can be asked and the knowledge that emerges by answering them. Based on that scheme, iSAT facilitates investigating the second and third order of questions regarding Comparison and Contingencies. Table 9.21 gives the category of questions that can be investigated with iSAT.

Table 9.21: Category of research questions that can apply iSAT

Category of RQ (Dillon, 1984)	Knowledge in question-answer (considering P and Q as Phases of iSAT)	Possible to visually inspect with iSAT constructs or patterns
Second order: Comparisons Comparative attributes of P and Q		
1. Concomitance a. Conjunction	Whether P goes with Q. - whether P and Q are associates	Yes – comparing transitions
b. Disjunction	- whether P and Q are alternative	Yes – switch pattern
2. Equivalence	Whether P is like Q, and wherein	Yes – comparing transitions
3. Difference a. Disproportion	Wherein P and Q differ -whether P is more/less than Q	Yes – comparing transitions
b. Subordination	-whether P is part/whole of Q	Yes – comparing strata
Third order: Contingencies Contingent attributes of P and Q		
1. Relation	Whether P relates to Q	Yes – comparing transitions
2. Correlation	Whether P and Q covary	Yes – align pattern
3. Conditionality a. Consequence	Whether or how if P then Q, or if Q then P Whether if P then Q, or what X if P.	Yes – arranging phases
b. Antecedence	Whether if P then Q, or what X then P.	Yes – arranging phases
4. Bi conditionality (causality)	Whether or how if P then Q and if Q then P	No

Based on the iSAT analysis flow presented, researcher can compare proportions at 4 different levels. For a given attribute represented as phase they can compare the strata. The transition and its patterns help to find relations between the attributes. For two different scenarios where similar data is analysed, the overall transition map can be compared. Further selecting phases based on attributes recorded across time can be used to investigate temporal variations too.

Researchers can answer RQs that focuses on explicating such transition patterns or further refine their RQs to conduct specific statistical analysis to establish such comparison and contingencies.

9.5.3 Collected Research Data that can be analyzed by iSAT

Technology tools in the teaching learning environment enable automated collection of various data. Some raw data are directly collected such as activity time log, resources used, survey responses (for example demographics survey), observation data, performance score in standardized test or validated rubrics, etc. While other data are computed from the raw data, such as total performance score from individual marks, engagement or affective parameters like frustration from observation data, etc. Dychoff et.al. (2011) compile a set of 6 questions in a meta-analysis and noted methods and tools of data collection used to answer them. iSAT can be utilised for 5 of those categories dealing with quantitative analysis. They focus on differentiating groups of students, differentiating learning offerings, consolidating relationships in data, use of attendance data, effectivity.

The researcher needs to consider the context, the RQs and the collected data, both at the beginning to determine the constructs of the iSAT model and thereby pre-process the data accordingly. Then later while interpreting the iSAT patterns to answer their RQs and get the insights regarding their context of research.

9.6 Analyzing applicability of iSAT

In the previous section, we listed some research cases highlighting how researchers have used iSAT to answer both confirmatory as well as exploratory research questions. To further illustrate the applicability of iSAT, we did a meta-analysis of the published research in IEEE Transactions of Learning Technologies. Our focus question was “What more observations can iSAT provide to the context of the following ET research studies with their already collected data?” We highlight some examples from that list and indicate the possible insights that iSAT patterns can visualize. Table 9.21 collates the data those studies collected, the results they reported in the context of their research and the transitions that can be visualized by using the iSAT tool.

The first two studies discuss technology tools developed that are applied in a teaching learning scenario. The study with WeFiLab (Cui et.al. 2012) has introduced a platform to learn concepts of networking. They have collected students’ details of performance, usability scores and usage parameters like access time, device used, etc. iSAT can highlight the patterns across the collected attributes and see if there are Aligned patterns between high score of performance and usability. Similarly the CoScribe system describes a prototype for combined work with print and digital document (Steimile et.al. 2009). While using iSAT, the time spent on the CoScribe system and perception of the system can be represented as the phases. If high time spent leads to low perceived value of system and vice-versa then it indicates the researchers to further look into the usability and usefulness of the system. Switch pattern can highlight this possibility in the dataset.

The next two studies introduce an educational intervention. The study with Geolearners (Clough, 2010) introduces a mobile social learning intervention. The transition in their dataset of the detailed students’ survey-questionnaire response can be traced by iSAT to find patterns across level of participation, technology used and level of learning experience reported. In another study dealing with effectiveness of a teaching intervention for the concept of Boolean logic (Weng, 2010), iSAT can highlight differences in patterns of control and experimental groups.

The fifth sampled study deals with evaluating and modelling mood during an online self-assessment activity (Moridis & Economides, 2009). Once the model is validated, iSAT can trace possible transitions of mood across the questions of the assessment tests.

Table 9-21 Applicability of iSAT sample research studies from Transaction of Learning Technologies (IEEE TLT) journal

Title	**Data collected**	**Paper reported**	**Transitions iSAT can visualize**
WeFiLab: A web-based WiFi laboratory platform for wireless networking education	Students' access time, score, place of access, device used, OS, Browser Usability scores	Distribution Average score	Trace transition of access time, logistics and usability score. Trace *Aligned patterns* of high performance and usability score.
CoScribe: Integrating Paper and Digital Documents for Collaborative Knowledge Work.	Time Likert response	Bar charts Comparative Bar chart of control and experimental group	Trace transitions between Task completion time and their perception of the system
Geolearners: Location-Based Informal Learning with Mobile and Social Technologies	52 item questionnaire to report Geocaching experience	Tabular information of response categories and qualitative analysis of learning experience	iSAT can trace transitions across level of participation - tech used - level of learning experience
Teaching Boolean Logic through Game Rule Tuning	Pre-post test score	Tabular information of T-test results in pre-post as well as experiment–control group	Trace score across 3 section of the test administered and highlight the difference between control and experimental group
Mood Recognition during Online Self-Assessment Tests	10 parameters regarding indicated mood, goal set, accuracy.	Modeling students mood	Check transitions of mood across questions

9.7 Discussion on applicability of iSAT

We analyzed five research studies to answer our focus question "What more observations can iSAT provide to the context with their already collected data?" We found that transition across various type of collected attributes can be looked with the help of the iSAT. While we identified possible attributes and strata from the collected data and could suggest transitions that can be explicated with iSAT, interpreting them in their context is beyond our scope. Hence, we claim iSAT is generalizable to any context which collect data with multiple attributes and each attribute can be stratified into groups. Those attributes can be considered as phases and each group in them as strata. iSAT visualizes proportions of strata and transitions across the phases. This model can assist to answer research questions that want to investigate comparisons or contingent of contexts with multiple attributes.

The current tool is limited to process transitions across three phases and each phase having a maximum of seven different strata. While it may seem like a constraint, a larger dataset can be tackled by selecting three attributes at a time as phases for analysis. Consider a scenario where an instructor gives five formative assessments where students are evaluated on a score of 10 in each assessment. Potentially, the instructor might want to see transition patterns across all the five assessments with each possible score as a stratum. That would lead to a maximum of 10^5 possible transitions to analyse from. Such high number would be difficult to interpret visually. To utilise the current iSAT tool, the instructor (user) can first select a subset of that assessments to define up to three phases. Similarly, modifying the stratification criteria can be a way to group the scores without losing essential context for interpretation.

Based on this analysis, we designed an analysis planner to assist the user to organise their data to analyse with the iSAT model. A pilot implementation was done with a simple form using google spreadsheet. It prompted the user to fill in the meta data of their context such as brief about their context, details of the collected data in that context and the possible Phases and Strata that they want to analyse in that dataset. Once the structure of analysis is determined the planner elicits possible research questions or hypothesis that emerge in the mind of the user based on the constructs of iSAT. We tested this approach with one researcher as user. That sample filled in context metadata form is presented in Table 9.22. It captures the values of the iSAT constructs and corresponding hypothesis that is generated in the context.

Table 9-22 Context metadata of a proposed study to use iSAT analysis

Details of Context	Instructor of EE733 - Solid State Devices (PG Basic Course) has implemented PIVOTeeING - A flipped approach (Problem solvIng Via instructOr mediaTed peer learING). We are evaluating the first cycle (second phase) of this course implementation. To answer the research question "What impact did the implementation of PIVOTeeING have on student's learning? " , we have chosen to analyse the end semester quiz scores. There are 3 questions in the end semester quiz.. The three questions are at different levels : Q1 is only looking at conceptual and mathematical reasoning , Q2 is adding to the diagrammatical reasoning to Q1, Q3 is combining Q1, Q2 and evaluating and comparing different scenarios. As the three questions are at different levels- We want to see how the students have performed at each level? How the performance changes as they move to the higher level questions? By looking at these patterns we might be able to design course elements for the student to perform at each level. The end semester answers are analysed with a rubric, consisting of 6 criterion each with 3 scales of performance. The important point to note that 2 criterion in the rubric are only applicable to question 2 and not the q1 and q3. I am planning to use iSAT to see the performance level of students in 3 questions at each rubric criteria.					
Details of Collected Data	Rubric score for Q1	Rubric score for Q2	Rubric score for Q3			
Data Type	ordinal	ordinal	ordinal			
Data Range	2 to 0	2 to 0	2 to 0			
Can the data be Stratified?	yes	yes	yes			
How many Strata are you planning for	3	3	3			
Details of Phase	Phase 1		Phase 2		Phase 3	
Name of Phase	Answer to Question 1		Answer to Question 2		Answer to Question 3	
Selected Data	final quiz					
Details of Strata in Phase	Strata name	criteria used to stratify	Strata name	criteria used to stratify	Strata name	criteria used to stratify
Strata 1	Satisfactory	Rubric	Satisfactory	Rubric	Satisfactory	Rubric
Strata 2	Unsatisfactory		Unsatisfactory		Unsatisfactory	
Strata 3	Poor		Poor		Poor	

Some of the RQs generated in the above example and its corresponding map to the construct is given below in Table 9.23. The researcher filled in possible iSAT maps in terms of the transitions required to study. For a particular transition map its relevance in analysis is described in the second column. The hypothesis based on that transition is presented in the third column. The bottom of the table has the specific criteria for stratification.

Table 9-23 Relevance and hypothesis of possible iSAT analysis

Possible iSAT to analyse	Relevance of iSAT in the context	Hypothesis that iSAT can assist to investigate
Q1C1-Q2C1-Q3C1	Performance levels of learners concept identification skill for problem solving across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor)	Most learners are able to achieve satisfactory level of concept identification for solution in context of JFET and NMOSFET than PNP Bipolar transistor
Q1C2-Q2C2-Q3C2	Performance level of learners in mathematical constructs recall for problem solving across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor)	Most learners are able to achieve satisfactory level of mathematical construct recall for at least some solution parts in context of JFET and NMOSFET than PNP Bipolar transistor
Q1C3-Q2C3-Q3C3	Performance level of learners in establishing link of mathematical construct and concept for problem solving across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor)	Most learners are able to achieve satisfactory level of establishing link of mathematical construct and concept for at least some solution parts in context of JFET and NMOSFET than PNP Bipolar transistor
Q1C6-Q2C6-Q3C6	Performance level of learners in justifying solution by linking appropriately (conceptual/diagrammatical and mathematical) across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor)	Most of the learners are unable to provide justification for solution by linking appropriately (conceptual/diagrammatical and mathematical) across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor)
Q1C1-Q1C2-Q1C3-Q1C6	Performance level of learners in all the 4 constructs in the context of JFET	-
Q2C1-Q2C2-Q2C3-Q2C4-Q2C5-Q2C6	Performance level of learners in all the 6 constructs in the context of NMOSFET	-
Q3C1-Q3C2-Q3C3-Q3C6	Performance level of learners in all the 4 constructs in the context of PNP Bipolar transistor	-

Criteria #	Criteria Name	Satisfactory
C1	Concepts of Semiconductor Devices	The appropriate concepts for the solution (assuming a solution path, arriving at sub-steps of solution, solution justification) have been appropriately identified
C2	Mathematical Construct (Level 1)	The appropriate mathematical construct for the solution (assuming a solution path, arriving at sub-steps of solution, solution justification) have been identified
C3	Mathematical Construct (Level 2)	The link between the mathematical constructs and the concepts have been completely established
C4	Diagram Construction (Level 1)	The appropriate band diagram has been constructed by utilizing all the information in the question
C5	Diagram Construction (Level 2)	The appropriate concept and mathematical construct is applied to derive the band diagram
C6	Solution Justification by linking appropriately (conceptual / diagrammatical and mathematical)	There is appropriately linking between the three (concept-mathematical construct- diagram) to eliminate unlikely scenarios and justify a particular scenario

Chapter 10

Efforts Towards Proliferation of iSAT and User Studies

After the concept of iSAT as a possible meso-level analysis technique was systematically developed, we wanted to proliferate the concept to the stakeholders. It is also in spirit of the design and development methodology which recommends to communicate with the community the developed output. In this chapter we give an overview of those attempts and the associated studies (see fig 10.1 for organization)

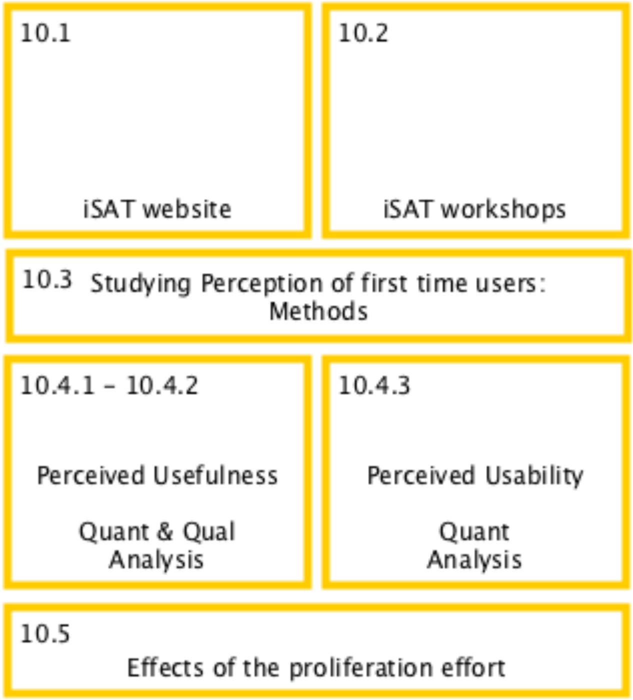


Figure 10-1 Organisation of chapter 10

We built a website to disseminate information of iSAT (www.et.iitb.ac.in/iSAT). The iSAT tool itself is web-based and open access. We offered introductory workshops during different academic conferences and teacher training programs to reach different stakeholders. Further our academic publications reported different aspects of the research focusing on iSAT such as its application in learning analytics (Majumdar & Iyer, 2014), development process (Majumdar, Alse & Iyer, 2014) and utility for instructors (Majumdar & Iyer, 2016).

10.1 The iSAT Webpage

The iSAT web page is accessible at: www.et.iitb.ac.in/iSAT. The "SATisfy your data" button gives access to the online tool (see Fig 10.1).

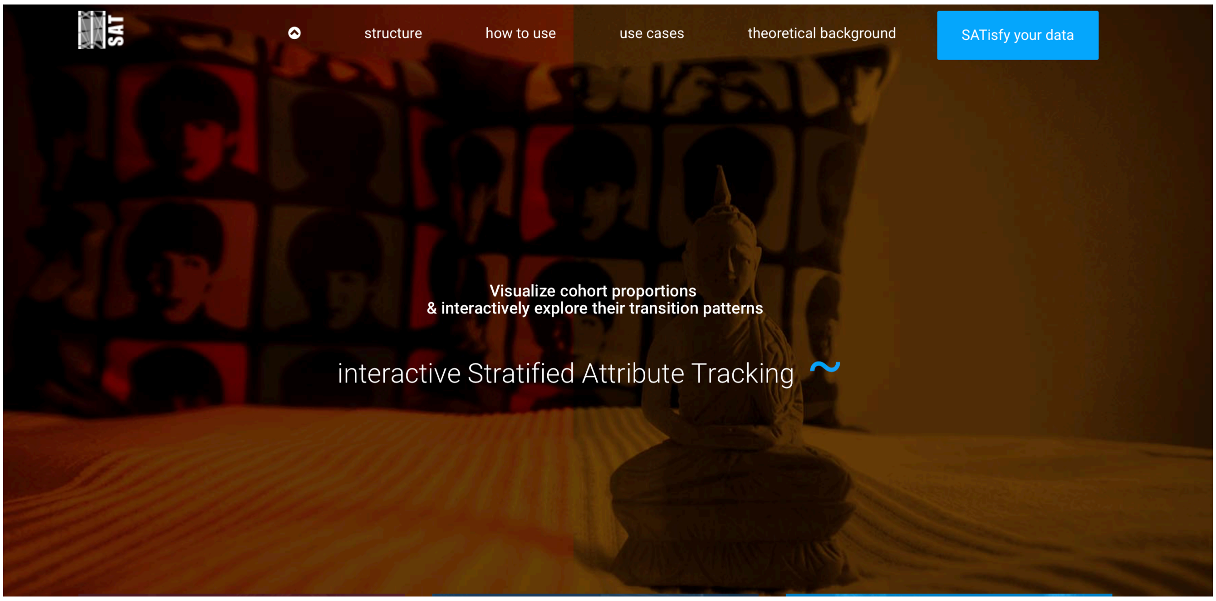


Figure 10-2 iSAT landing page

The HTML5/JS based tool can directly work on the user's browser (client end) without uploading data on any server. There are main three panels, one to upload data, one to display the iSAT diagram and the other to interactively search patterns. An interactive on-demand demonstration of the user interface elements is given for the users (see Fig 10.2).

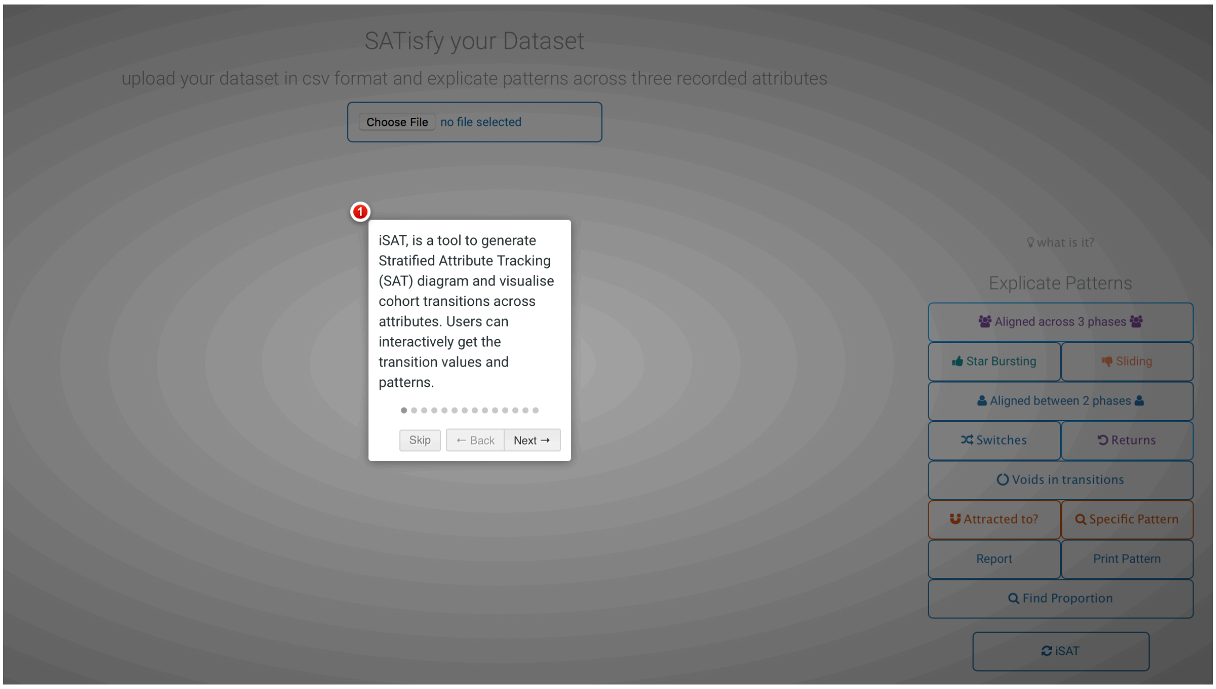


Figure 10-3 Interactive demonstration of the UI elements for iSAT tool.

10.2 Design and implementation of the iSAT workshops

Four workshops to introduce iSAT were conducted during different academic conferences in 2015 and 2016. The overall objective of all the workshops was to introduce iSAT and the online tool for meso-level analysis of the data that stakeholders deal with in teaching-learning scenarios. We describe the workshops as conducted in chronological order. The worksheet used during the workshop is presented in Appendix III.

10.2.1 MEET 2015 Workshop

Theme of MEET 2015: Mentoring Educators in Educational Technology (MEET) 2015 was a program to facilitate Indian engineering college instructors to reflect on their instructional practices by conducting classroom action research. This was a 6 months blended program where participants visited for a face-2-face session.

MEET 2015 Website:http://www.et.iitb.ac.in/~jkmadathil/et4et/programs.html

Objective of iSAT workshop: The session on iSAT focused on analyzing cohorts in the classroom and the what are the limitations in analyzing with multiple histograms.

Duration of workshop: 1.5 hrs.

Participants: There were 14 participants. 11 of them were in-service engineering college instructors with minimum of 2 years of teaching experience. They were from Computer Science, Electrical and Mechanical engineering departments. Among the participants, 2 had a PhD degree, 3 were pursuing part-time doctoral program in their respective domains, and 3 were Mtech students of Computer Science.

Presentations and Resources:http://www.et.iitb.ac.in/~rwito/iSAT-meet.html

Reflections: This was the first workshop to introduce iSAT to users who were outside my own research group. The participants were a mix of instructors and masters' students in computer science who had varied research experiences. The participants engaged with the iSAT tool and could visualize sample datasets and retrieve transition information from the visualization. During the MEET program the participants were introduced to planning research studies in their own classroom scenario. They were suggested possible use of iSAT to trace transitions in the data that they would collect. During the workshop, we found the need of creating a worksheet which would assist the first time users to explore the iSAT tool in a structured manner. Further feedback from the users and their perception is presented in section 10.4.

10.2.2 T4E 2015 Workshop

Theme of T4E 2015: Technology for Education (T4E) is a yearly international conference which is hosted in Indian. It attracts researchers working on different aspect of technology in education. Instructors from different Indian institutes and industry experts also participates in this forum. In 2015, NIT Warangal hosted the seventh T4E.

T4E 2015 website: http://www.ask4research.info/t4e/2015/

Objective of iSAT workshop: Our proposal of the iSAT workshop was accepted as one of the 4 workshops to be conducted in T4E 2015. The objective was to introduce iSAT as a visual learning analytics tool to trace educational dataset.

Duration of workshop: 1.5 hrs. Due to further demand the workshop was repeated for the participants who missed the first offering due to parallel workshop sessions.

Participants: There were total 48 participants including both offerings.

Presentations and Resources: http://www.et.iitb.ac.in/~rwito/iSAT-T4E.html

Reflections: The workshop design was modified from the MEET workshop by including more structured hands-on activity based on the principles of Immersivity and Pertinency (Warriem et.al. 2015). It started with the participants working on a brief Peer Instruction task and the data that is generated during that activity was taken to introduce the iSAT concept and tool. Further the participants were given a worksheet on analysis problem where they used the dataset from a previous study (Kothiyal et.al. 2014).

10.2.3 LaTiCE 2016 Workshop

Theme of LaTiCE 2016: The fourth International Conference on Learning and Teaching in Computing and Engineering (LaTICE) 2016 was held at IIT Bombay. It had three themes, Computer Science and Engineering Education research, Secondary School Computer Science and ICT in Education.

LaTiCE 2016 website: http://www.et.iitb.ac.in/latice2016/

Objective of the iSAT workshop: iSAT workshop was announced during the conference for any participants who were interested. The objective and design of the workshop was not changed from the T4E 2015 offering.

Duration of workshop: 1.5 hrs.

Participants: There were 4 participants. 2 of them were from industry.

Presentations and Resources: http://www.et.iitb.ac.in/~rwito/iSAT-T4E.html We had used the same material used during the last offering in T4E 2015.

Reflections: Due to the less number of participants, we mainly conducted the workshop in a discussion mode. The industry participants gave inputs regarding the usefulness of tracing the transitions in the dataset with respect to the kind of data they deal with. The relevance of the visualization based analytics tool was emphasized by the industry participants. While they appreciated the fact that data doesn't need to be uploaded on any server and thus helping to maintain privacy, but from their functional point of view they expressed the need of further querying the dataset based on the transition pattern which is not there in the current tool.

10.2.4 ICCE 2016 Tutorial

Theme of ICCE 2016: International Conference on Computers in Education is a flagship conference of the Asia-Pacific Society for Computers in Education. In 2016 the 24th ICCE was hosted by IIT Bombay. The conference theme was *Think global act local: Contextualizing technology - enhanced education*. This conference too had prominent international participation.

ICCE 2016 website: http://www.et.iitb.ac.in/icce2016/

Objectives of the iSAT workshop: iSAT was introduced as an Interactive Visualization for Cohort Analysis in Educational Dataset. The workshop was designed with keeping researchers as the primary participants. Our intent was to introduce the three levels of analysis (Macro-Micro-Meso) and how cohort analysis is possible in educational dataset with the help of the interactive iSAT tool.

Duration of workshop: 4 hrs.

Participant: There were 30 participants.

Presentations and Resources: http://www.et.iitb.ac.in/~rwito/iSAT-ICCE.html

Reflections: The workshop had international participation with participants from 4 different countries which included India. Though the focus was mainly on the researchers, many instructors from engineering colleges across India also participated. As an ice-breaker and to elicit the participant's conception of learning analytics, we used a iSquare protocol (Hartel, 2014) and asked them to draw in response to the question “What is Learning Analytics?” and to complete the sentence “I have analyzed learning data to…”. We updated and expanded the worksheet activities to include separate tasks which focus the users to retrieve different information regarding strata, phases and transitions from the created visualization. Such tasks were linked to the questions that the user wanted to answer.

10.3 Studying perception of first time iSAT users: Methods

The workshop introduced the iSAT model and the web tool to first time users. We wanted to study *What is the perception of usefulness and usability of iSAT for the first-time user?* (EQ2)

10.3.1 Method of study

- **Evaluating perceived usability of iSAT**

  System Usability Scale (SUS) - System Usability Scale was developed by Brooke (1996) as a survey scale to quickly and easily assess the usability of a given product or service. There exist other extended usability surveys (see Table 1 in Bangor et.al, 2008), but we choose SUS for the following reasons:

  - The study is both easy to use by both study participants and administrators.
  - It is technology agnostic and flexible enough to assess wide range of interface technologies.
  - Provides a single score that can be interpreted easily for anyone even without detailed domain knowledge of human factor and usability
  - It is a reliable (reliability is 0.85, according to Table 1 in Bangor et.al. 2008) and non-proprietary, making it a cost-effective tool as well.

The 10 item SUS survey was given to the participants at the end of the hands-on workshop.

- **Evaluating perceived usefulness of iSAT**

  TAM2 - We investigate three constructs from the Technology Acceptability Model 2 (Venkatesh and Davis, 2000.) to evaluate the perceived usefulness of iSAT for a meso-level analysis. Three of those constructs are, *Intention to use*, *Perceived usefulness* and *Job relevance*. There were 8 items selected from the TAM2 survey for the perceived usefulness survey.

Analysis of the semi-structured interviews - Inductive qualitative analysis was conducted on the interview data collected during the research. The transcript of the interview was created. A set of statements on the same context was considered as a unit of analysis. The open coding is done for the unit of analysis. The codes are synthesized to provide themes during focused coding stage.

10.3.2 Instruments for data collection

For quantitatively understanding we have used validated survey questionnaires as the instrument to evaluate the usefulness and usability of iSAT. To answer EQ1, we had chosen constructs from the Technology Acceptability Model 2 (TAM2) (Venkatesh & Davis, 2000) and adopted eight items related to the intention to use (Q1 & 2), perceived usefulness (Q3–Q6), and job relevance (Q7–Q8). For EQ2, we have used SUS (Brooke, 1996) as our instrument. We also received verbal feedback from workshop attendees, poster and paper presentations audiences and had follow up personal communications.

10.3.3 Participants and sampled survey data

There were 14 participants in the first training session during MEET workshop. The T4E training workshop had total of 42 participants in two sessions, out of which 28 of them were instructors at college level. During ICCE there were 22 participants.

For the quantitative study the response of participants from different workshops were pooled in. There were a total of 71 participants, who entered the demographics data. Among them, we received 27 responses for the questions from the TAM2 survey and 35 SUS responses.

We further interviewed 3 participants (1 researcher and 2 ET industry professionals) after the LaTiCE workshop regarding usefulness. The researcher was a post doc researcher currently in an ET project and the industry professionals were product managers in ET industry. Later 2 researchers were interviewed after giving the demo of iSAT. Both of them focused on discipline based educational research. One of them had extensive experience on handling eye tracking data and another handled the analysis of a nationwide Physics Olympiad contest. Further 3 researchers were communicated over email as they expressed interest regarding iSAT. Their response also expressed certain utility of iSAT from the users' perspective which were included for analysis.

10.3.4 Analysis

The TAM2 items had 7-point Likert's scale response, and the SUS survey asked 5-point Likert's response. To answer EQ1, Likert's scale data was aggregated in three groups: agree (combining responses 5 to 7), neutral (response 4), and disagree (combining responses 1 to 3). We further analyzed the transitions of response from one group to another across the survey items by using iSAT. This helped to explicate patterns across the three constructs chosen from the TAM2 survey. The interviews of the researchers were analyzed to understand aspects of usefulness for their context.

For EQ2, we considered the total SUS score and evaluated its usability with respect to empirical results of SUS score (Bangor et al. 2008). We examined the reason that participants gave corresponding to their response to each items to find the major perceived reason.

10.4 First Time User's Perception of iSAT

10.4.1 Perception of Usefulness: Quantitative analysis

The distributions for the usefulness survey items are presented in Figure 10.4.

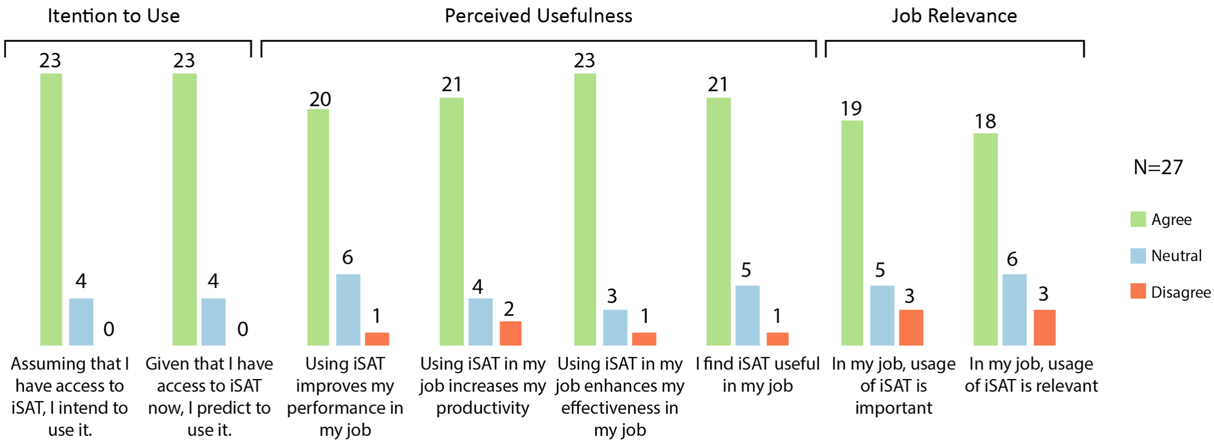


Figure 10-4 Results in TAM2 survey

Among the responses, eight (67%) showed intent to use iSAT given a chance to access the tool assuming or given a chance to access iSAT. Fifty-eight percent of responses confirmed perceived increase in performance and productivity, whereas 75 % perceived enhanced effectiveness and 50 % found iSAT useful in their job. Forty-two percent perceived usage of iSAT was important in their job, and 25 % agreed it was relevant. Figure 10.5 shows the iSAT visualization of the transitions in the usefulness constructs.

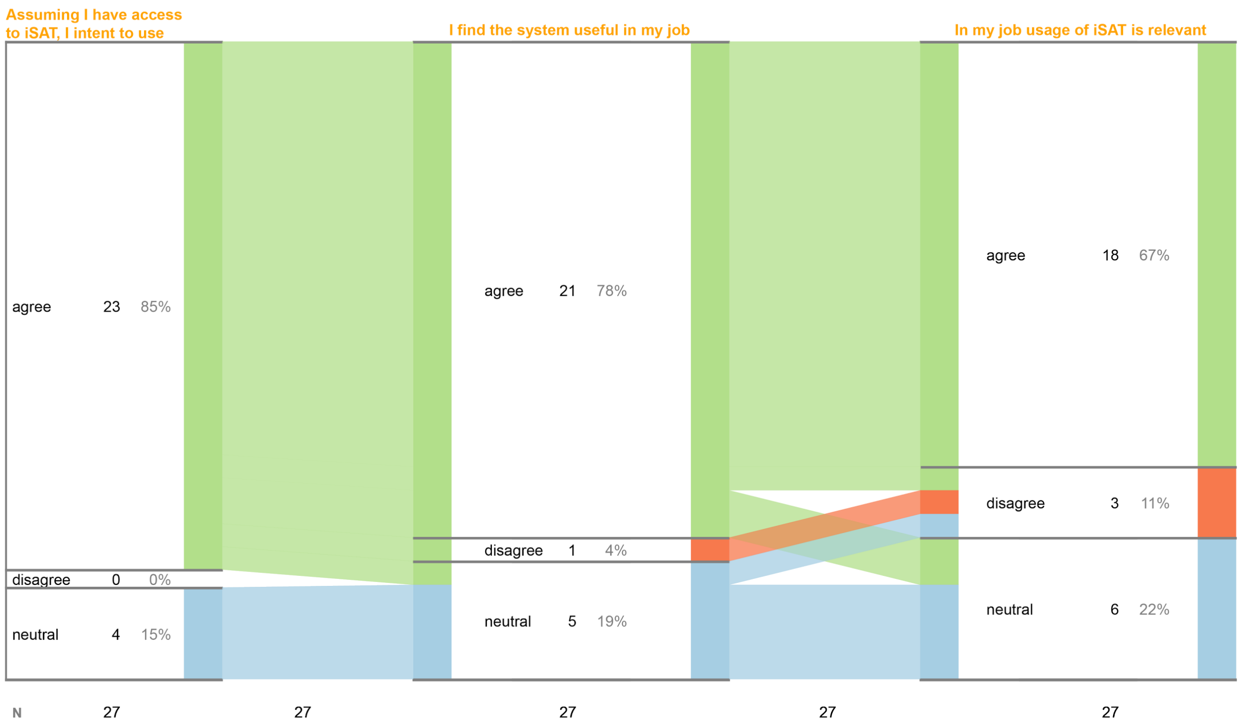


Figure 10-5 SAT diagram of transitions in survey

Analyzing the transitions in survey response through iSAT (see figure 11), we further found 66.66% of the participants were consistently agreeing across all the three constructs. 15% participants were neutral across all the response. None of them disagreed to all of the items.

Within the construct of intention of use, there were two items. Twenty-two responses (81.5 % of total and 95.6 % of the responses which agreed in individual items) agreed in both the items, and two responses (7.4 %) switched options across these two items, one from being neutral to agreeing and the other vice versa. Three (11.1 %) were neutral for both the items. None of the responses disagreed about the intention of use. This established that participants intended to use iSAT. Only one response (3.7%) consistently disagreed to the perceived usefulness and job relevance of iSAT, though it also presented intention to use.

10.4.2 Perception of Usefulness: Qualitative analysis

Analyzing the data of 6 researchers and 2 persons from the Educational Technology industry also helped in understanding perceived usefulness of the iSAT model.

- iSAT is useful for analyzing large datasets
  The visualization technique was perceived useful only when the number of records were large. "what I am finding most interesting is ... how particular bracket movement can be seen. That is very difficult when the data is very large or you don't get to see that happening. that is very interesting."
- iSAT visualization helps in visualizing cluster information
  One of the researcher highlighted the differences in the visualization of SAT and iSAT diagram as read from the reported papers on iSAT. Based on that he mentioned in his research on cluster analysis it was essential to "include in the graph the percentage of the cluster that are transitioning to other clusters." perhaps in addition to just represent the proportion through width.
- Intent to try out with 'other' data
  Each participant showed an interest to try out the tool further with 'other' data. In some context they wanted to carry out an analysis from data apart from that shared during the workshop and other they wanted their own data to explore the methods.

10.4.3 Perception of Usability: Quantitative analysis

The mean SUS score was 71.58 (s.d. 16.66, n = 35). The score reflects that iSAT is an acceptable system. The participants mentioned that “the tool (iSAT) can be used for other types of analysis than Statistical analysis”, “it’s easy to understand the GUI”, “no need of an expert to learn to use the tool, because as you start exploring the tool, the transformation in the pattern itself gives an idea of the cohort”, “could use the functions efficiently which gave clear results”, “results seems fairly correct”. Other feedbacks were: “without using for couple of times we cannot answer it (whether cumbersome to use)”, “practice will make it user friendly”, “(cumbersome to use) may depend on how many parameters”, “(I felt confident) because it is shown how to use”, “few things which anyone can get through”, “It is not complex, but without a guide it might be little difficult to figure out certain functions.”

One of the participants who attended the T4E workshop used the tool the next day to present her data during the paper session. Later we had corresponded with her on mail to gather details of how she utilized iSAT. To quote her “I have used the tool for analyzing the POGIL INDIA data that I have collected from my classrooms. … this tool (iSAT) made a way for me to show my data in a proper form.”

10.4.4 Discussion on user perception results

The evaluation of first time users indicated an overall interest to use iSAT. Some workshop participants were interested by the visualisation itself. Others who had some ongoing data to analyse, felt transition patterns might provide a new perspective to the context of their own data. While that perception often made iSAT model an interesting analysis to try out, an iSAT workshop still remained essential for introduction. Even for the researchers they wanted to familiarise the constructs and then map it to their context. In that respect developing case study of applying the iSAT model might help future users.

Further specific user tasks-based evaluation is required in future to understand the detail of the usability issues of the web based tool and conduct statistical tests on the user performance on the tasks.

10.5 Effects of the proliferation effort

We used three avenues to proliferate the idea of interactive attribute tracking as a meso view analysis of educational dataset. They were

- hosting a web page which gives information regarding iSAT and access to the free online iSAT tool.
- designing and conducting workshops to introduce iSAT,
- academic reporting through peer reviewed conferences and journal publications.

The paper and poster presentations in other academic events initiated dialogues amongst the interested collaborators. One participant in the T4E workshop used the iSAT tool to present a finding the next day during the conference session. During ICCE 2015, the work on the instructor's' use of iSAT for understanding dynamics in a PI activity, initiated a collaborative work with researchers from HKU which later culminated to a research paper investigating trends of performance of early learners' phoneme detection skills. During Diagrams 2016 the graduate symposium could introduce the technique to researchers from other domains of research too. A graduate researcher from the domain of HCI, investigating to check efficiency of specific graphing techniques on task performance, discussed the possibilities of using iSAT to trace transition patterns of reaction times and accuracy of task.

The outreach activities like conducting workshops gave an opportunity to interact with stakeholders and potential users of iSAT. The interaction with the people who were interested in iSAT was quite encouraging during the graduate research period. Apart from focusing on exchanges of areas for development and research it was also motivating experience to validate the work.

Chapter 11

Discussion

This research work **conceptualized a model and tool for visual analysis of cohorts in educational datasets**. The work was informed by studying the need for analyzing transitions of cohorts in the context of educational data sets. Our approach was to facilitate qualitative analysis of quantitative data with an interactive visualization. We used Design and Development Research (DDR) methodology, we designed and refined iSAT, a model of meso-level analysis and developed a web tool based on that model.

11.1 Our contributions

- **Establishing the need and context of meso-level analytics with visualization** In this thesis we focused on analyzing transitions of cohorts in teaching-learning scenario. Such analysis provides a meso-level perspective of the collected dataset. We collected empirical data from educators which highlighted the need for cohort level data. For instance, instructors want information on different groups in their class such as, students who had taken a course as an elective vs who had it in their regular curriculum, the ones who had prior knowledge vs others without any, etc. Many analyses that the instructors wanted to do involved deeper probing into the datasets. There are techniques which assist the users to cluster and classify their data and define cohorts. But they are often difficult for the instructors and novice researchers to interpret. Learning dashboards help them to visualize information for easy access and interpretation, but we did not find any of them which focus on transition patterns that might exist in the datasets and visualize them. Most of the visualizations in a typical dashboard were like bar charts, pie charts and scatter plots which do not support visual analysis of transition patterns. This need and context analysis synthesized the design goals for the model and tool for meso-level analysis.

- **Conceptualizing a meso-level analytics as iSAT model** We designed the Interactive Stratified Attribute Tracking (iSAT) model to trace transitions of cohorts as a specific analysis possible at the meso-level. We conceptualized the constructs, methods and visualization associated with that model over three stages of the design and development phase. The first two focused on generating and refining the iSAT model and the third cycle implemented it as a web based tool to assist users to analyze based on iSAT model.

- **Developing a web based tool to assist iSAT users.** We developed a free web-based iSAT tool accessible at www.et.iitb.ac.in/iSAT . The HTML / JS based tool helps users to parse their data and visualize the transitions. Further it assists interactive exploration of patterns that exist in the transition map. The user doesn't need to upload their data on any server, but can visualize their data on their own browser itself. This implementation of the tool with processing capabilities at the client browser end, helps to maintain the privacy of the data that the user wants to analyze.

- **Establishing usefulness and usability of iSAT.** We conducted formative evaluation of the different iSAT versions across the design and development phase. At the end of development our working solution was evaluated by the stakeholders. We conducted usefulness analysis of 12 use cases across 9 different scenarios. iSAT helped to track and understand transition patterns across time or across different attributes of the collected data. The users utilized these patterns to build a descriptive model of the dynamics in their context. Some of those models were further used to compare different interventions or take specific instructional or research decisions. The insights based on iSAT analysis were published in 6 peer reviewed conferences, 1 journal paper and another doctoral thesis. Further we conducted 4 workshops to introduce iSAT to the first time users. At the end of each workshop users filled a usefulness and usability perception in TAM2 and SUS survey respectively. According to the TAM2 survey 67% of the participants (n=27) perceived that they intended to use iSAT as it was useful and relevant to their job. The average SUS survey score was 71.58 (s.d. 16.66, n=35) which indicated the iSAT tool is acceptable on the usability scale.

- **Proliferation of iSAT for meso view analytics** To proliferate iSAT we built a web based tool. We introduced the techniques of analyzing data with iSAT tool in 4 hands on workshops which were attended by a total of 96 participants. Further 12 research studies applied iSAT to analyze and report their research findings.

- **Instantiated DDR methodology to implement learning analytics development research** We didn't find any suitable methodology that can guide learning analytics development research. Therefore, we adapted Design and Development Research (DDR) methodology for this purpose. Based on the purpose of inquiry of research, we proposed 3 different types of research questions: need and context analysis question, design questions and evaluation questions. We investigated these questions in the corresponding phases of DDR.

11.2 What works with iSAT: claims and evidence

iSAT gives a unique perspective of tracking cohorts across attributes or time based on the multi-attribute data collected in educational context. Visualizing the proportions and patterns of transitions assists users to analyze dynamics from a meso-level perspective in any given context. The Table 11.1 gives the compilation of the claims and evidence from our research work.

Table 11-1 Claims and evidences

	Claims	**Evidence**
1	iSAT model assists visual analysis of transitions at meso-level.	12 studies applied the iSAT model of analysis and obtained insights regarding the cohorts of learners in their specific context.
2	Analysing transitions informs researchers and instructors about the dynamics across time and attributes in a teaching-learning scenario. This assists them to build a descriptive model of the context of the data.	5 reported studies.
3	iSAT model can be used to take research and instructional decisions based on transition patterns of the data in context	4 reported studies.
4	iSAT model can be applied for analysing learners sub groups for RQs of type Comparisons and Contingencies with multi-variate data	Analysed 5 research studies from IEEE TLT to find possible transitions that can be analysed
5	iSAT tool is usable	Average SUS score is 71.57 (s.d. 16.66, n=35)
6	iSAT model is acceptable by the first time users.	67% of users perceived that they intended to use iSAT as it was useful and relevant to their job 15% users were neutral across the survey items NO users disagreed to all the items for iSAT

Role of the iSAT model:

The constructs of the iSAT model (*Phases, Strata* and *Transition*) help user to analyze their dataset from a meso-level perspective. For example, the researcher who was studying the effects of instructor mediated peer learning in a basic engineering graduate course, mentioned that the ideation process, following the methods to identify iSAT constructs in their own context, itself helped to think about different aspects that can be investigated in that context. This helped to frame research questions in the context like *"How the performance changes as they move to the higher level questions [from mathematical reasoning to evaluating different scenario]?"*.

Transitions as a construct also helps to develop conjectures regarding the dynamics of the different cohorts present in the context and take decisions. For example, thinking in terms of transitions assisted the research to speculate "*Most of the learners would be unable to provide justifications for solution by linking appropriately (conceptual/diagrammatical and mathematical) across the 3 problem contexts of (JFET, NMOSFET and PNP Bipolar transistor). By looking at these patterns we might be able to design course elements for the student to perform at each level".* Thus the iSAT method enables users to look beyond single attributes and analyze transitions across attributes. They can compare and interpret proportions of different strata in a single phase or different patterns across phases.,/.

Role of the iSAT tool and interactive visualization:

The iSAT tool made it easier for the user to execute the methods associated with generating and analyzing the meso-level view. The implicit relationships in the tabular data is explicated by the visualization. It can then be used to report insights in the context where the data was collected and take decisions based on it.

Literature provides 3 perspectives on how such visual analytics systems assist the user (Arias-hernandez, R., Green, T. M., & Fisher, B, 2012). From a Distributed Cognition perspective, the interactive visualization system can become a cognitive amplifier. Considering the standard cognitive abilities of individuals, an interactive visualization can be looked upon as a cognitive prosthetic, i.e., they can assist by extending the standard cognitive limits. Finally, according to Activity Theory, they can behave as cognitive mediators.

11.3 Limitations

iSAT includes visualizing transitions in the dataset as computed by membership of the records to some preset group (strata) in each attribute (phase). The concept neither defines any patterns from a mathematical modelling perspective nor does the analysis involve differentiating emerging transition patterns statistically.

The current version of the web-based tool visualizes transitions across only three attributes at a time with the dataset uploaded as CSV file. The optimization of the algorithm for the web-based tool is not taken in the scope of the current work. Further at this stage of tool development, the usability testing of iSAT is done with first time users only. The test is based on perception surveys through validated instruments such as SUS and TAM2. These surveys were taken immediately after introducing iSAT in a 1.5-h workshop session. That might have an overwhelming effect, which resulted higher agreement in intention to use. Additional detailed testing of usability is required to determine to what extent the web tool assists the users with specific analysis tasks.

11.4 Generalizability of iSAT

The approach of interactive stratified attribute tracking can be used in educational contexts where the focus is on tracking transitions of cohorts. The applicability analysis indicates the research context, type of research questions and the data which can be analyzed by iSAT. The insights from the transition pattern can be utilized in that context either to model the dynamics of cohorts, or to compare different teaching-learning scenarios or take executive decisions in research design or instruction.

Going beyond educational datasets, any contexts which warrants a meso-level perspective with respect to analyzing group membership and transitions of records can possibly apply iSAT. Researchers might analyze transitions of grouped records across attributes or across time. For example: studying transitions between accuracy of different tasks given for testing in HCI studies can give insights about the tasks and the participants.

The visual representation of iSAT can be used independently to visualize datasets by highlighting proportions of subgroups (as represented by strata) for any data attributes (as represented by phases). It can further track proportion of change in that group membership across different attributes. For instance, a study on evaluation of various farming systems using Farm Assessment Index (FAI) derived from a set of indicators explored iSAT visualization to convey the following:

There were more than 30 indicators used in the study. In some cases, a single variable captured a set of (more than one) indicators and, in some cases, a set of variables collectively captured a single indicator. iSAT visualization helped to present this pattern pictorially for an easier understanding. (see figure 11.1, Nutrient excess N, P and K in the third phase collectively captured nutrient use efficiency in the second phase)

FAI is an aggregate of all the indicators. Each indicator has its own weightage in the FAI. When an indicator is missing in a case study, the weightage of missing indicators is shared among other indicators. The transition chart helps in representing this redistribution of weightage from the missing indicators to the available indicators. (see Figure 11.1, Energy use efficiency and chemical use efficiency is dropped and the weightage of rest of the factors are redistributed)

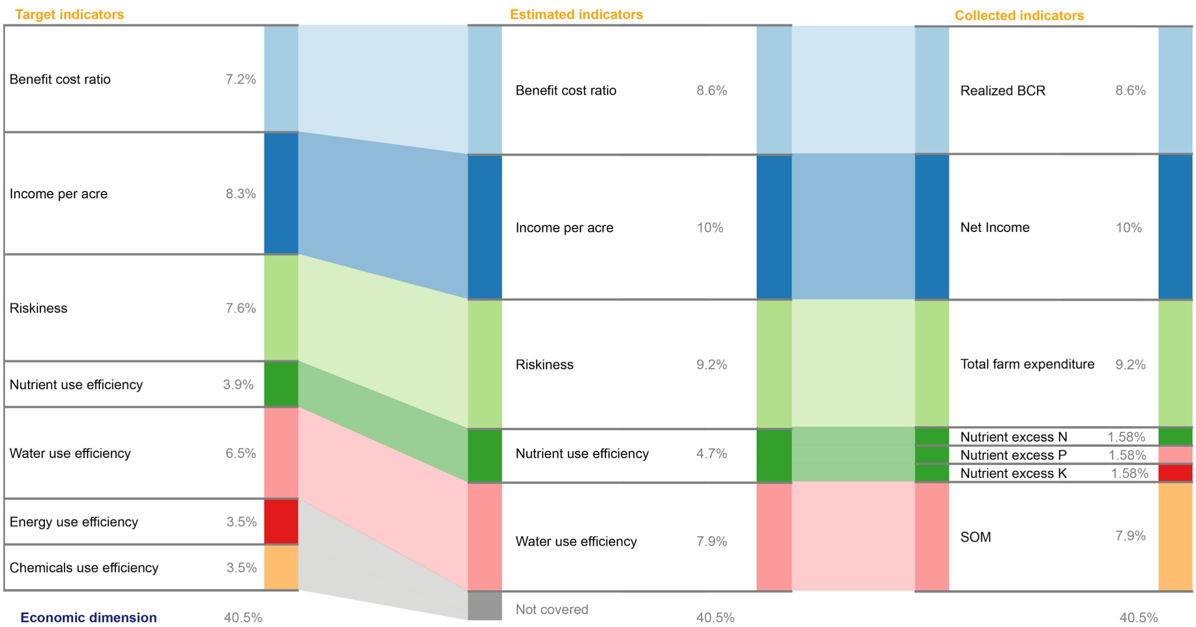


Figure 11-1 iSAT visualization used for depicting proportion of sub-groups

11.5 Future research and development possibilities

There are multiple research and development threads that can follow the current work. Some of them are as follows:

11.5.1 Educational Technology research

Applying iSAT to analyze dynamics of other teaching-learning scenarios.

The thesis work illustrates application of iSAT model in 9 different scenarios. Further scope remains to apply the iSAT model in other ET research studies in different contexts. For example, investigation can be done to find effectiveness of iSAT to analyze drop-outs in MOOCs. Instructors can also visualize online resource usage pattern across the different periods of the MOOC. Such studies in different context are required to understand the nature meso-level perspective in those context and its advantage.

Evaluating effective utilization of iSAT model for different user profiles.

More investigations are required to understand how accessible the iSAT model is for different user profiles within each group of stakeholders. For example, how experienced instructors use iSAT for measuring classroom engagement of their learners or how effectively does a MOOC instructor use the engagement transition to decide their instructional strategy. Similarly, for researchers as user one can find to what extent does the meso-level analysis with iSAT model and tool help novice researchers to take different perspective of analysis for their research context and data. The insights from these studies can help to further refine the tool as well as update the introductory iSAT training module.

Study to what extent does the users' experience of analyzing data and iSAT training workshop affects the quality of use of iSAT model and tool.

Across the case studies discussed in this thesis, there were varying degree of support that was provided to the iSAT users. Some just required assistance in exporting the final visualization to include in their publication draft (before we had implemented the report generator feature). While others had discussions and email correspondence while planning for organizing the data for structuring the constructs of the iSAT model. But in each case all the interpretations were done by the primary user who collected and analyzed the data. From these variations of assistance that the user seeks, couple of research question arise:

- What extent does the researcher's prior knowledge of analyzing student data influence their use of iSAT?
- How effectively does the specific workshop activities and tool demonstration assist the first time users to take a fresh perspective in their research context from the meso-level view?

Developing constructs other than transitions to study meso-level information regarding cohorts.

We believe that looking at transitions of cohorts is one of the analysis that is possible from the meso-level perspective. Future research can design other models of analysis at the meso-level.

11.5.2 Diagram and HCI research

Generating design alternatives to convey transition information.

Our implemented visualization and interaction idiom should be considered as one possible implementation that highlights transitions for possible meso-level analytics. Future work can redesign this visualization to represent the current constructs of iSAT. For example, the transition band can be represented as a gradient of the colours picked for the strata that it links. The research can investigate the effect such design changes have on the comprehension of users during any task. Further research can conceptualize other meso-level constructs and corresponding visualization and interaction idioms for analytics.

Developing analytical indices for comparing different iSAT diagrams.

The iSAT representation gives an overview of the transition dynamics that is inherent to the dataset. There is a scope of introducing indices to differentiate the nature of patterns that exists in different datasets. For example, in the Figure 11.2 we see the performance transition maps of learners between Alliteration test and the Rhyme tests. During Post-test, performance in alliteration and rhyme are more aligned, whereas in the Retention test the transition patterns cross over between different strata. Formalizing analytical indices can further assist users to describe or compare transition dynamics and assist in inferencing.

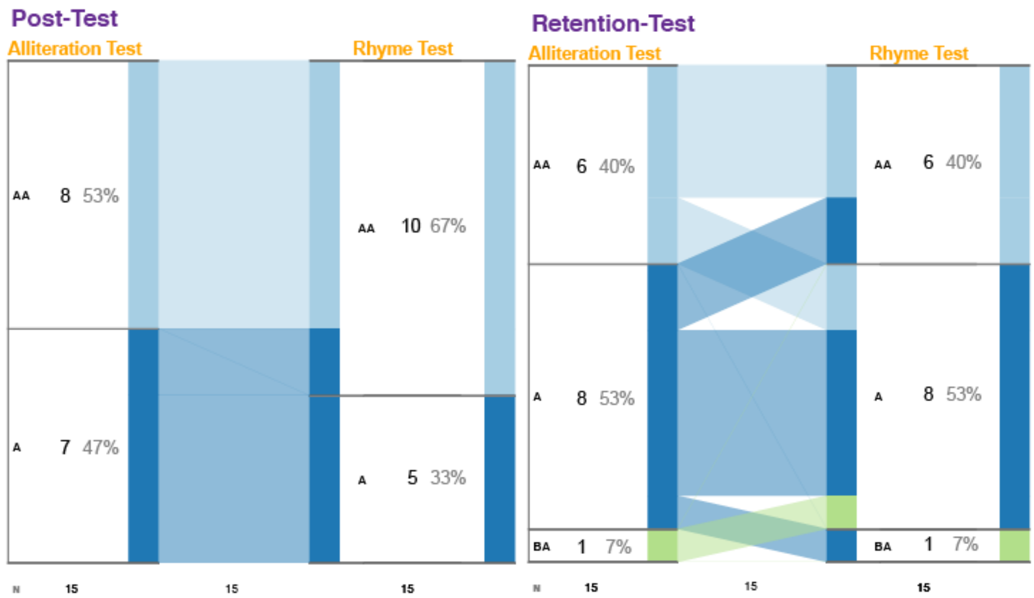


Figure 11-2 Two iSAT with different transition patterns

Empirical studies to find how interaction idioms of the web-based tool affords specific meso-level analysis task.

Learning the iSAT model of analysis along with the tool usage in their context of data seemed quite overwhelming for the first time users, in just an hour and half long workshop. So we collected data limited to only perception surveys of those participants. Future studies can analyze user data generated while they interact with the iSAT tool with data from their own context and given a specific analysis task.

Analyzing the interaction with iSAT model and tool from a distributed cognition framework

The current work look at the development and evaluation of the meso-level analytics from an information science point of view as applied in the context of educational datasets. Future work can investigate the usefulness of the iSAT model from the perspective of distributed cognition (Hollan, J., Hutchins, E., & Kirsh, D. 2000). One may analyze the socio-technical system that involves the stakeholders such as instructors or researchers, their context, the analysis tasks involved and the web-based iSAT tools to answer how do they interact to generate insights.

11.5.3 Development

Feature development in iSAT tool - The current version of the tool doesn't track more than 3 attributes. In the next version of the tool we could implement further visual analytics functions like, choosing own attributes from the dataset, sorting and filtering option of the strata and exporting the generated visualization in multiple image formats. One can also enable visual data mining to export specific data of the selected cohorts. Based on the existing tool an API can be developed to integrate with existing LMS and MOOC platforms. It would help the users to analysis data within the same platform as a continuous workflow without changing applications.

11.6 Conclusion

In this thesis we designed the iSAT model to analyze any multi-attribute educational dataset by visualizing the transition patterns that exists in. Based on this model, a web based iSAT tool was developed that assists users to parse their data to generate the visualization and interactively analyze their transitions. This provides a meso-level perspective of cohorts that exist in the specific scenario of analysis. We analyzed how iSAT model was used in 12 cases across 9 different teaching-learning scenarios by both researchers and instructors. iSAT assisted to build descriptive models of those teaching-learning scenario based on transition dynamics of the collected attributes and further compare different implementation cases with in a scenario. It was used to refine or explore new research questions in ET research contexts and to update instructional strategies or decisions in any teaching learning context. We conducted 4 introductory iSAT workshops. The result of the post workshop first time users' perception survey concluded that iSAT was useful for both researchers and instructors for analyzing data in their own context and the web-based tool was usable.

Appendix I
List of Visualizations depicting transitions or flow in dataset

Histogram (Bar charts)

Histogram visualized as bar charts gives the aggregate frequency of different categories of data (see Ioannidis, Y., 2003 to get a historical account of Histogram). For example, it can indicate aggregate accuracy levels for each question response of the class (see fig 1).

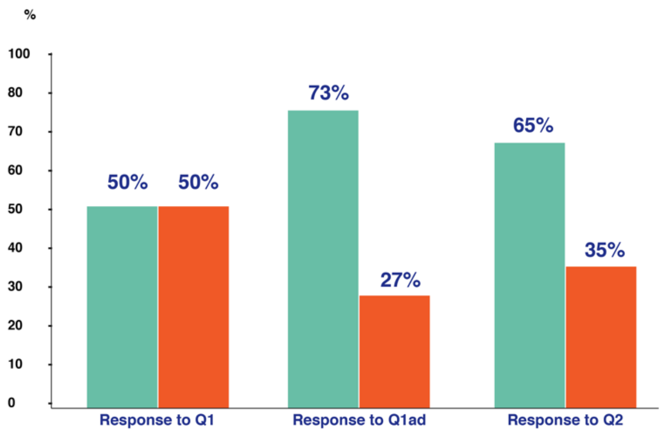


Figure 1: Histogram of accuracy in three questions

Though histogram provides frequencies of independent datasets whose data can be binned, it is not able to trace the migration of proportion across the bins. For e.g. in fig above we do not know what proportion of accurate responses in question one changes to in correct response in question two.

Parallel Coordinates

Given a multi-attribute dataset, Parallel coordinates is a powerful visualization to find patterns across multiple attributes (Inselberg, 1985;2009). Each record is drawn as a line across the parallel axes (see fig 2). The intersection of a line and an axis denote the value of the corresponding record for that axis variable.

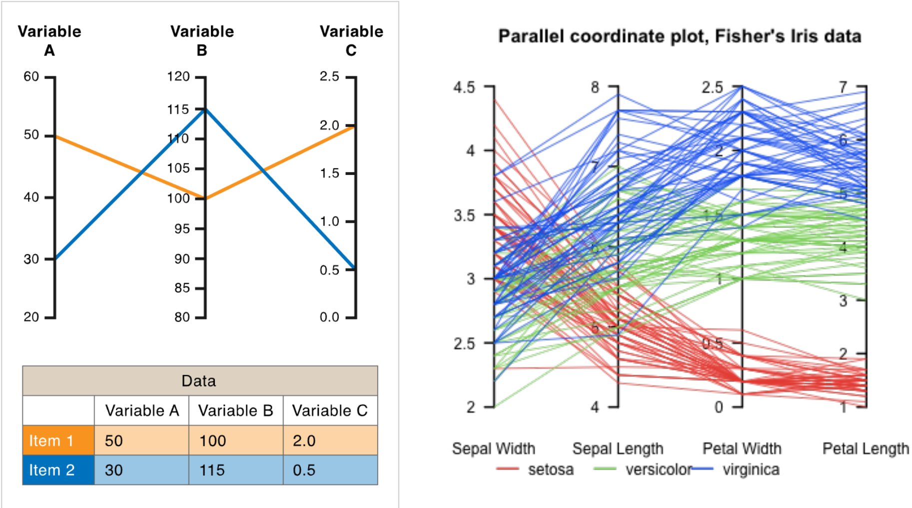


Figure 2: Fig Parallel coordinate plot from
http://www.datavizcatalogue.com/methods/parallel_coordinates.htmlhttps://upload.wikimedia.org/wikipedia/en/4/4a/ParCorFisherIris.png

Given any interactive system users can possibly trace each record and its corresponding values in each variable. But this visualization doesn't group records according to the variable values and hence frequency of the data in a particular range of variable value is not represented in this diagram.

Sankey Diagram

Sankey diagrams are traditionally used to visualize the flow of energy or materials in various networks and processes (Riehmann et.al. 2005). Example is given in figure 3.

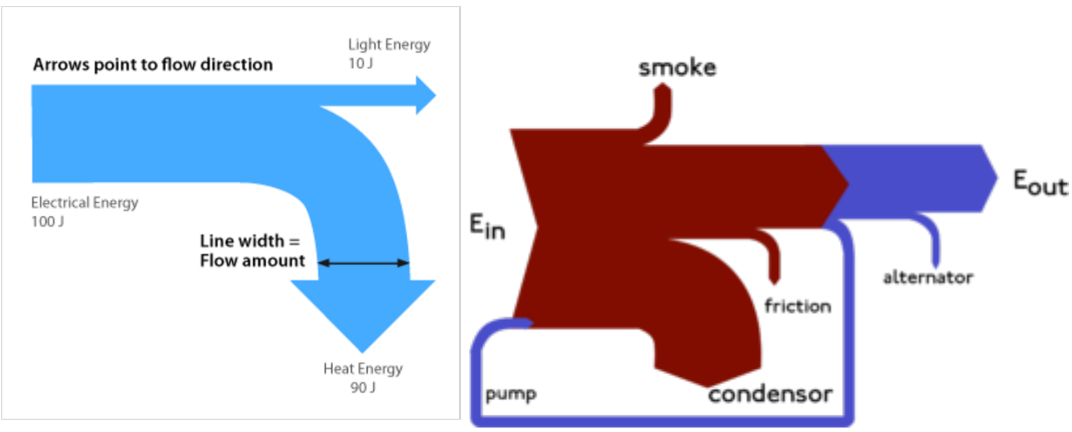


Figure 3: Sankey Diagram fromhttp://www.datavizcatalogue.com/methods/sankey_diagram.html
https://upload.wikimedia.org/wikipedia/commons/thumb/1/11/Sankeysteam.png/300px-Sankeysteam.png

This visualization has an arrow element which indicates the flow and typically it denotes the total input energy and various proportions of its utilization or loses. In the educational context the analogy can be drawn for analyzing dropout in any course. But it doesn't help to represent and analyze group membership of learners across different groups.

Circular plot

Circular plots were proposed to quantify global migration flows across a period of time (Abel, G. J., & Sander, N. 2014) (see fig 4).

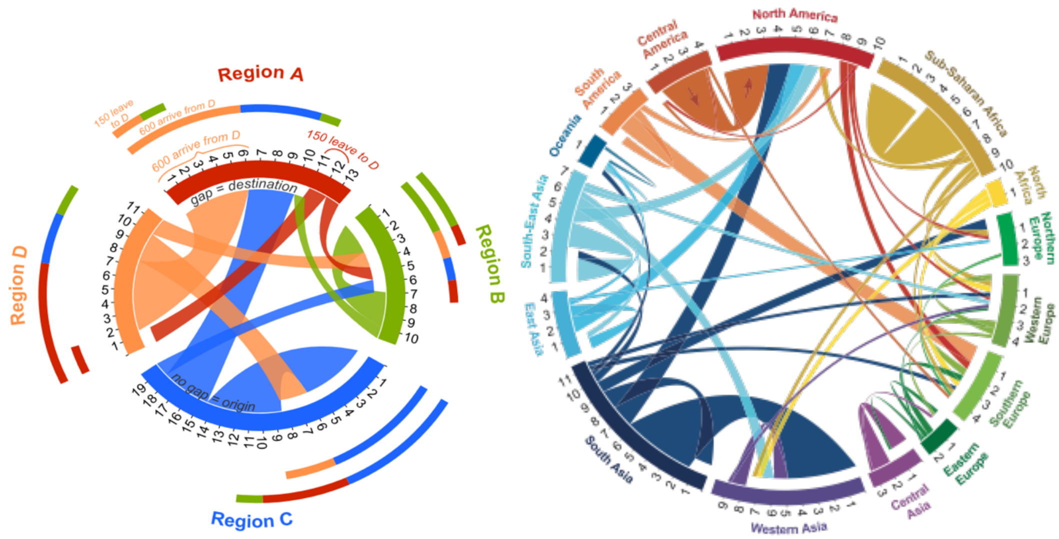


Figure 4: Circular plot

The plot highlights migration proportions from region A to B. Charles Minard flow map (see fig. 5) is a classic visualization which also indicates dynamics of the Napoleon's army while it travelled from Italy to Russia. It predates this category of Sankey diagram and circular plot. Tufte (2005) points out that six variables were captured within this map. The two most essential variables are: 1. The size of Napoleon's troops is encoded as the thickness of the line at any given point in time. 2. There are (in this case geographical) points or nodes where significant changes happened.

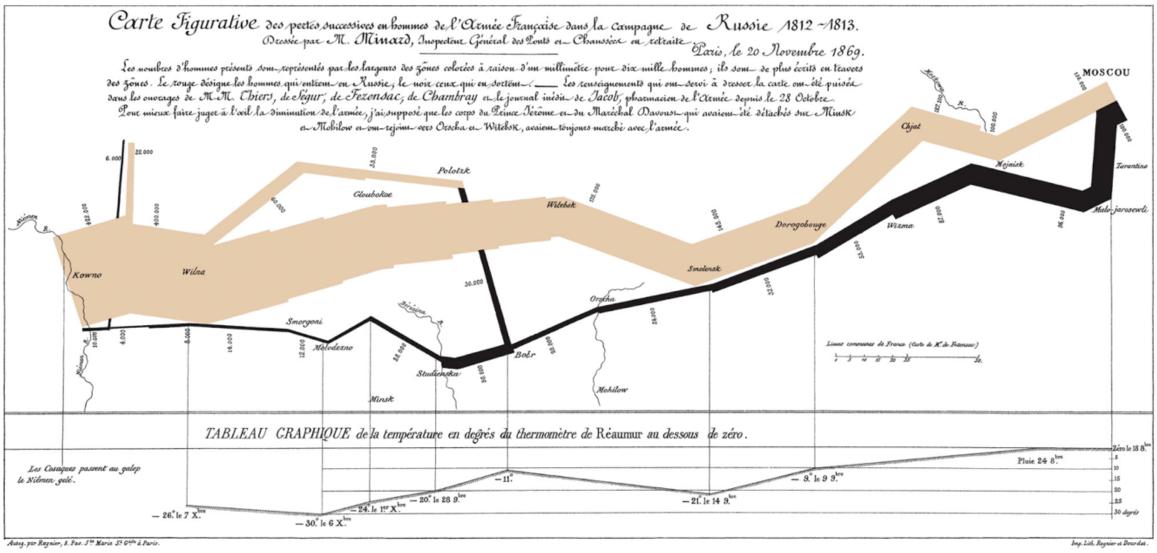


Figure 5: Charles Minard's flow map of Napoleon's army
from https://upload.wikimedia.org/wikipedia/commons/2/29/Minard.png

Steam Graphs / ThemeRiver

Steam graphs are used for "simplifying the user's task of tracking individual themes through time by providing a continuous 'flow' from one-time point to the next" (Havre, Hetzler and Nowell, 2002). The graph displays frequencies of categorical data across the period of time.

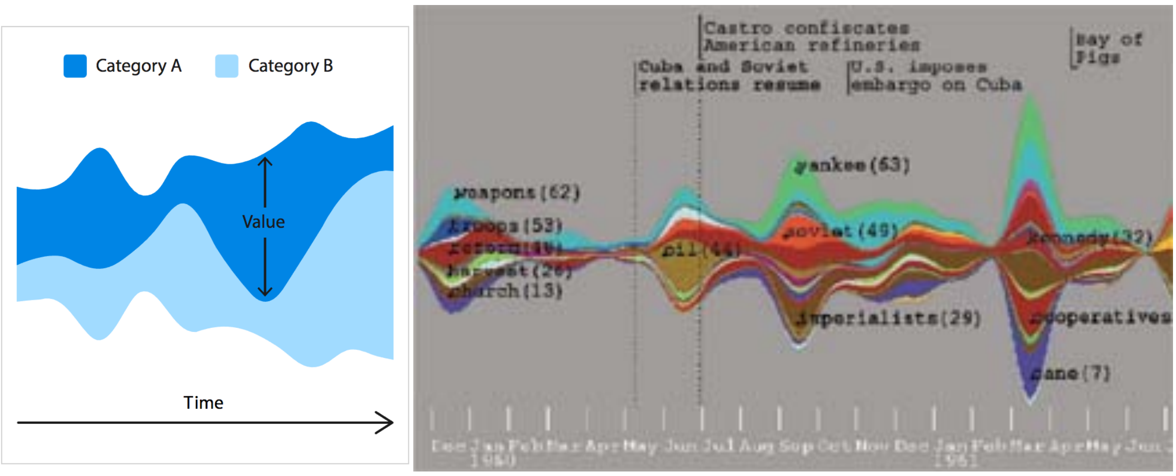


Figure 6: ThemeRiver-visualization-showing-documents-about-the-Cuban-Missile-Crisis
https://www.researchgate.net/profile/Maria_Cristina_Oliveira4/publication/262329119/figure/fig6/AS:295137147146275@1447377587754/Figure-5-ThemeRiver-visualization-showing-documents-about-the-Cuban-Missile-Crisis.png

The categories represented in the Themeriver graph remain the same throughout the length of the graph.

Alluvial Diagram

Alluvial diagram is developed to highlight and summarize the significant structural changes (Rosvall & Bergstrom, 2010).

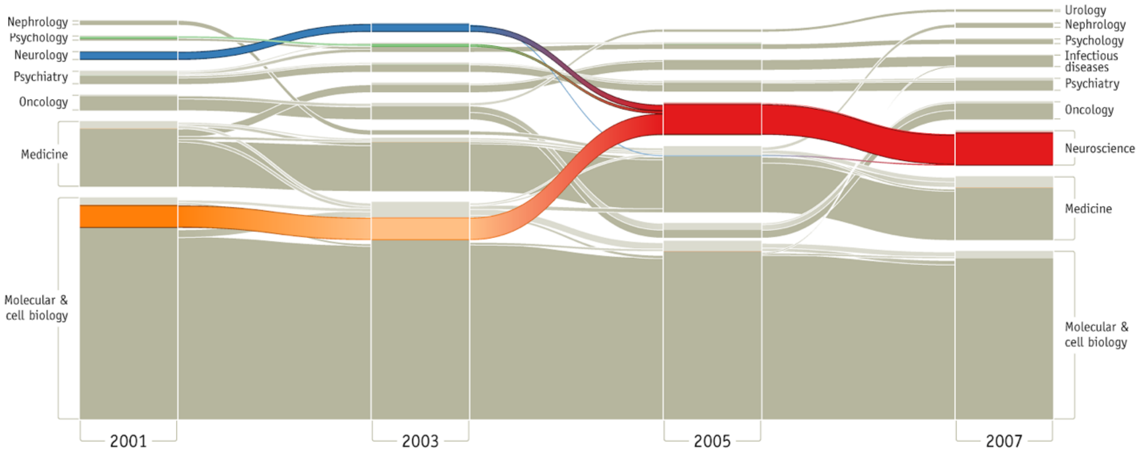


Figure 7: Alluvial diagram highlighting the emergence of the neuroscience stream
https://upload.wikimedia.org/wikipedia/en/thumb/9/96/NeuroAlluvial2001-2007-691x273.png/400px-NeuroAlluvial2001-2007-691x273.png

Parallel Sets

Kosara et.al (2006) proposed Parallel sets visualization to interactively analyze categorical data.

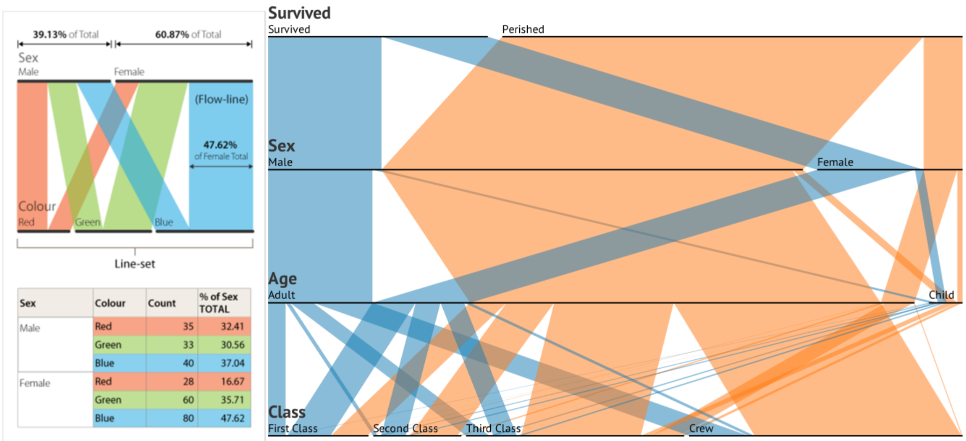


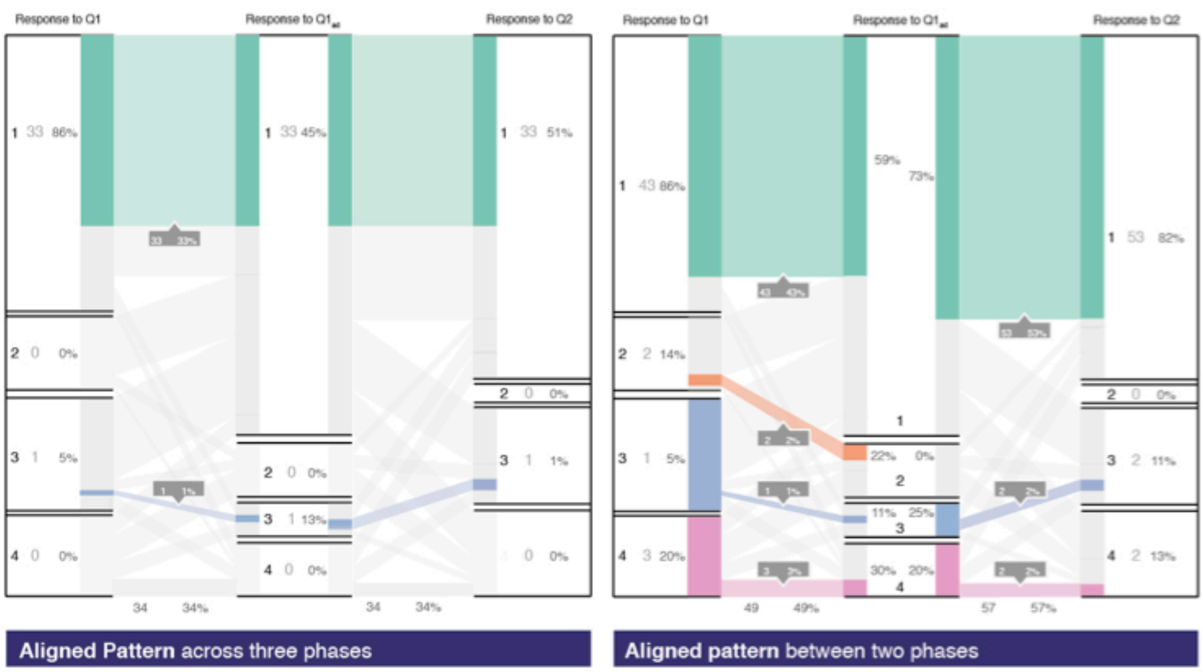
Figure 8: Passengers of titanic visualized by parallel set

Appendix II

Patterns in PI response dataset and how instructors can interpret them.

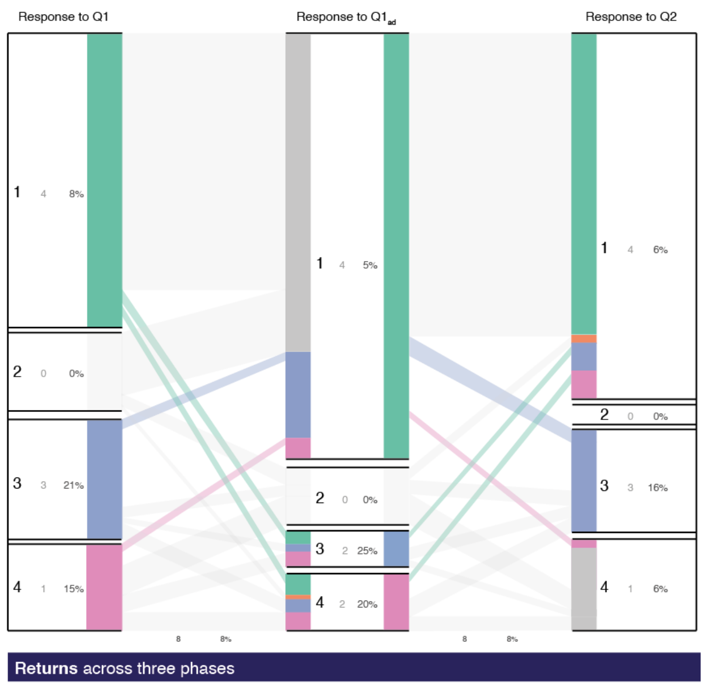
iSAT explicates the rich transition patterns in the three phase isomorphic PI activity response. The structure of the visualization gives instructor an overview of the pattern and the interactive tool then allows them to explore further details about those transitions. We explored all the 64 possible 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).

Aligned Patterns



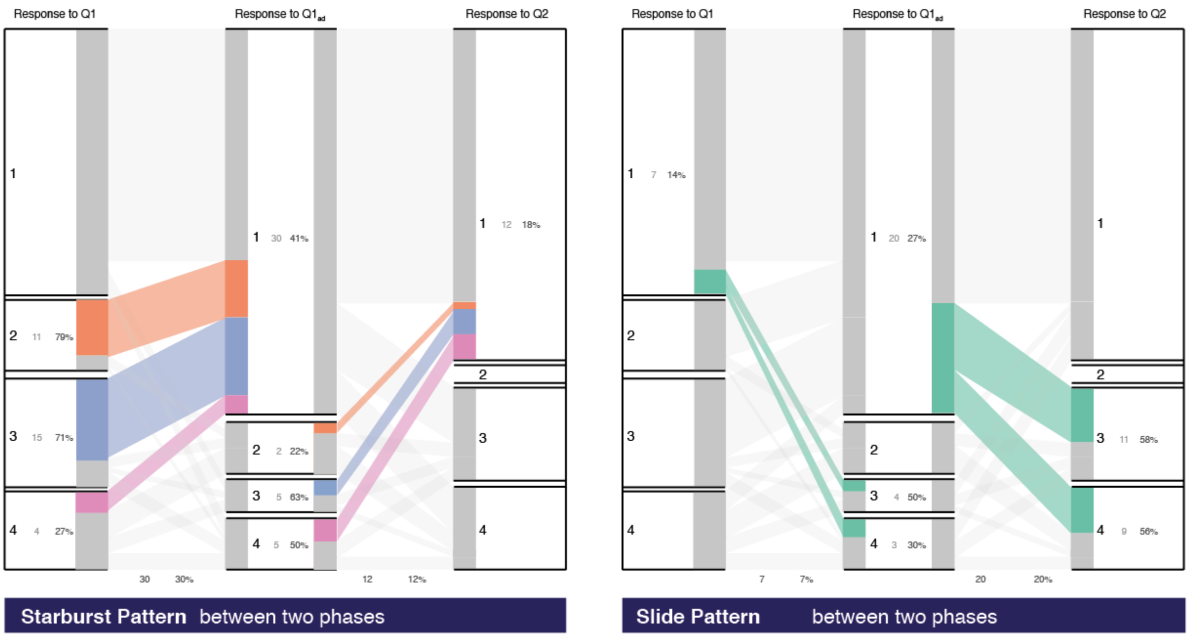
Aligned cohort remains in the same strata across phases. A bigger population of Aligned correct would probably indicate most students had the concept right and hence consistently answered correctly across the voting phases. The instructor can take it as a cue to go forward and introduce the next topic. An Aligned cohort to incorrect responses indicates that the cohort requires attention towards learning the concept, as they fail to answer both the isomorphic questions correctly across three phases of voting. For example, in our dataset 34% of the population voted the same choice across 3 phases with 33% consistently answering the right option and 1% consistently answering incorrectly without even switching their response from option 3 (see Fig 9a). If the Aligned incorrect population proportion is considerably more, the instructor then knows that the cohort is always stuck in the alternate conception linked to option 3. Further Fig. 9b 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.

Returns Patterns



The portion of the population who gives an initial response and changes it in the second phase but later return 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

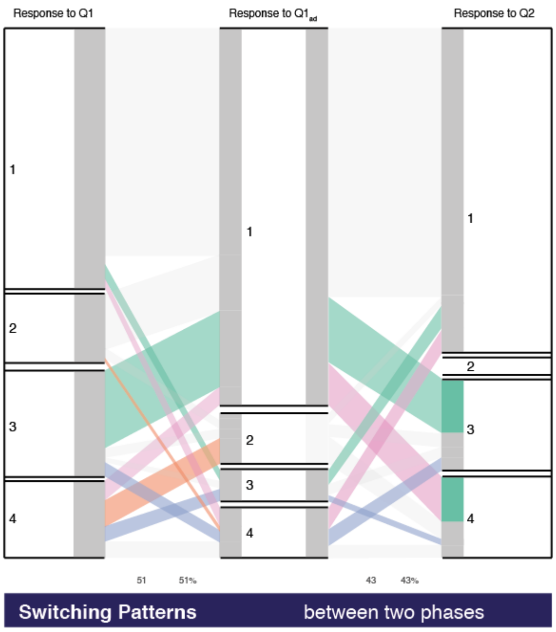
Starburst and Slide Patterns



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 incorrect in the first phase but go on to become correct in the next phase, they highlight the starburst pattern (see Fig 11 a). In our dataset, 30% of the students Starburst between Q1 and Q1ad and 12% from Q1ad 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.

A portion of the cohort that transits from a desirable stratum in the pre-phase to a less favourable 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 11b 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.

Switching Pattern

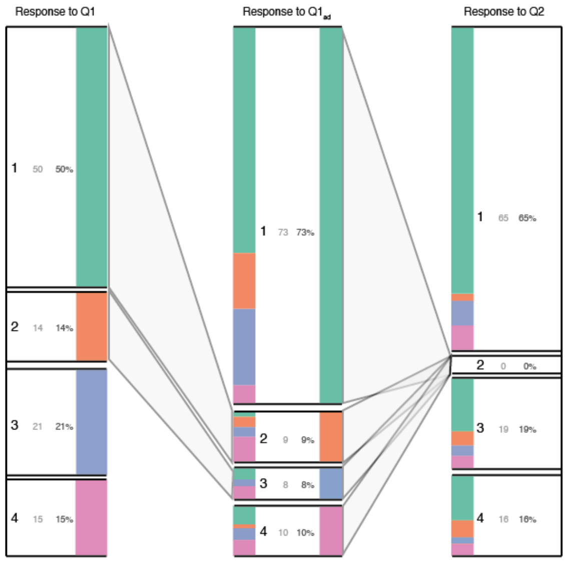


Between two strata a portion of one cohort can transit to the other across phases. A pair of such cohort represents a Switching pattern. Figure 12a highlights the switching patterns in our dataset. While 3% of students who gave answer as option 3, changed their response to option 4, an equal percentage of students switched their response from option 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 that there exists 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.

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 transitioned 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 of the incorrect response options and can correspondingly decide which alternate conception can be addressed in the post PI discussion.

Void Pattern



Void patterns in the dataset

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 the incorrect option 2 during re-voting (see Fig. 12b). 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 exist after the intervention. In our regenerated dataset proportion of option 2 as response in Q1ad decreases with respect to proportion in response to Q1. In response to Q2, none of the learners choose that. Linking this 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.

Appendix III

iSAT worksheet used during hands-on workshops

iSAT: A Visual Learning Analytics Tool To Trace Educational Datasets
Worksheet

Objective:
The objective of this worksheet is to assist learners in the process of learning the affordances provided by iSAT, an interactive Visual Learning Analytic Tool, in cohort analysis.

About the Worksheet:
This worksheet contains:

1. Stepwise Instructions to use iSAT
2. A mandatory exercise to be done during workshop

The exercise will have associated resources (which is provided in the Workshop Kit), and are explained along with the description of the exercise.

Once you have done the mandatory exercise, save its copy in the desktop and inform a volunteer who is present in the lab.

Stepwise Instructions on use of iSAT

Step 1: Go to the iSAT page by clicking on iSAT.html available in the “iSAT Workshop Kit” available in the desktop.
Note: You are advised to use Google Chrome to see best results

Step 2: You will be able to see a window similar to the one shown in Fig 1 below.

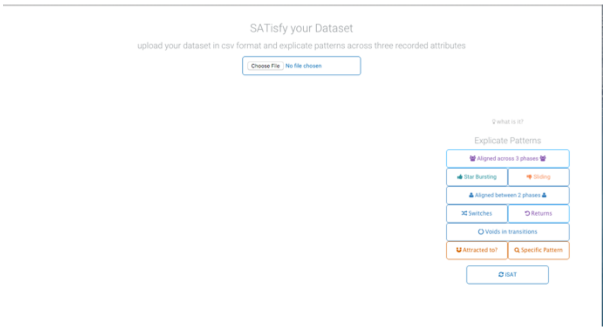


Figure 1: iSAT Landing Page

Step 3: Click on the “Choose File” button (Fig 2) and select the appropriate file from the Workshop Resources folder available in desktop

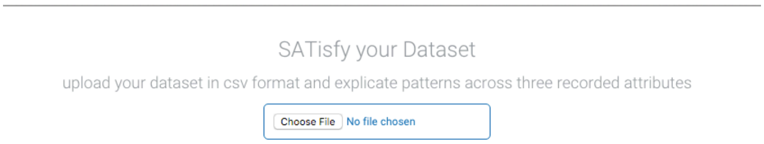


Figure 2: Data Selection Process in iSAT

Step 4: On loading the file you will see the transition patterns (as shown in Fig 3)

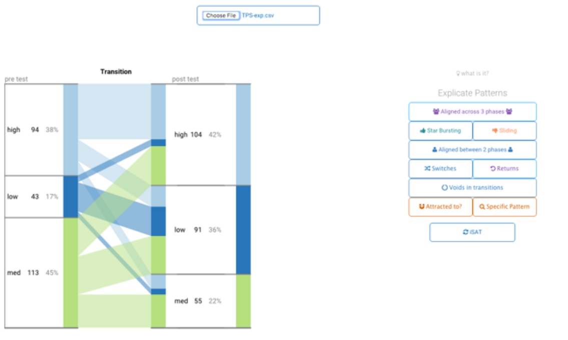


Figure 3: iSAT patterns

Use the side buttons or click on the strata/transition within the iSAT to learn more about the group transitions.

MANDATORY EXERCISE

The mandatory exercise allows you to perform learning analytics using iSAT for a given educational data set. This has to be performed inside the workshop. The workshop instructors will provide the cue on when to start the mandatory exercise.

Associated Resources:

Please check whether you have the following resources within the "iSAT Workshop Kit" folder.

iSAT-ICCE.html : The presentation slides of the workshop on iSAT at 7th IEEE International Conference on Technology for Education (T4E2015)

iSAT.html : The iSAT tool

Inside the main folder there is a subfolder titled resources. It will have:

TPS-control.csv : The csv file containing pre and posttest distribution of students who were part of the control group in a Think-Pair-Share intervention for a CS101 classroom.

TPS-exp.csv : The csv file containing pre and posttest distribution of students who were part of the experimental group in a Think-Pair-Share intervention for a CS101 classroom

ITiCSE-TPS.pdf : The research paper which had reported the findings of the intervention in the conference ITiCSE

About the Intervention

Think-Pair-Share is an active learning strategy that encourages collaboration and deep thinking among the learners. The researchers of this intervention were investigating the effectiveness of Think-Pair-Share in the learning of introductory computer programming course in a large classroom (2 batches with more than 150 students per batch).

They had divided the class into two groups – experimental and control, with the experimental group getting the TPS intervention while control group had same material taught in a more traditional way. More details can be found in the paper ITiCSE.pdf

Activity 1: **Identifying characteristics of Phase**

File to use: TPS-control.csv
Q1: How many students from control group achieved high marks in the pre-test?
Ans:

Q2: What percentage of students from control group performed low in the post-test?
Ans:

Q3: What is the ratio of low performers to high performers for the post-test in the control group?
Ans:

File to use: TPS-exp.csv
Q4: What percentage of students from experimental group achieved high marks in the post-test?
Ans:

Q5: What percentage of students from experimental group performed low in the pre-test?
Ans:

Q6: What is the ratio of low performers to high performers for the post-test in the experimental group?
Ans:

Q7: Verify Question:
Will you be able to get the same information (i.e. answers to questions) from a Histogram of mark distributions for experimental and control group?

Activity 2: **Identifying characteristics** of **Transitions.**

File to use: TPS-control.csv
Q1: How many low-scorers in pre-test within control group improved to high-scores in the post-test?
Ans:

Q2: Is this statement about the control group True: "More than half of the medium scorers in pre-test showed low performance at the end of post-test"
Ans:

Q3: Identify the percentage of people who have transited from a medium-score state in pre-test to low and high score states in the post-test?
Ans:

File to use: TPS-exp.csv
Q4: How many low-scorers in pre-test within experimental group improved to high-scores in the post-test?
Ans:

Q5: Is this statement about the experimental group True: "More than half of the high scorers in pre-test scored high even at the end of post-test"
Ans:

Q6: Identify the percentage of people who have transited from a low-score state in pre-test to medium and high score states in the post-test?
Ans:

Q7: Verify Question:
Will you be able to get the same information (i.e. answers to questions) from a Histogram of mark distributions for experimental and control group?

Activity 3: **Identifying patterns in Transitions**

File to use: TPS-control.csv
Q1: What is the percentage of learners showing same level of performance in the pre-post tests within the control group?
Ans:

Q2: What is the percentage of learners show a drop in performance to low in the post test within the control group?
Ans:

Q3: Find the ratio of upward moving learners to downward moving learners within the control group?
Ans:

File to use: TPS-exp.csv
Q4: What is the percentage of learners showing similar performance in the pre-posttests within the experimental group?
Ans:

Q5: What is the percentage of learners showing a drop-in performance to medium in the post test within the experimental group?
Ans:

Q6: Find the ratio of upward moving learners to downward moving learners within the experimental group?
Ans:

Activity 4: **Comparing two iSATs**

Q1: Does TPS have an effect on the low performers of Pre-Test? (Hint: Find ratio of upward transitions of experimental to that of control)
Ans:

Q2: What is the ratio between transitions low-high in control group to the same in experimental group?
Ans:

Q3: Compare and contrast the effect of TPS on high achievers?
Ans:

Activity 5: **Reflection on iSAT**

For answering the below question consider yourself as either a teacher or an educational researcher first.
Role that you are taking (Bolden appropriate choice): Teacher / Educational Researcher

Q. Reflect on how you have used iSAT till now to "understand the effect of TPS intervention in the learning of students in an introductory Computer Programming course". What information and insights did the iSAT provide you about the TPS intervention?

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