Visualization and User-Interaction techniques for Reflective Learning with user-related data

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Abstract

Reflection done over the past experiences can lead to new insights about those experiences, and it can further help us to improve our future experiences. Reflective learning has been found to be an effective technique to learn from and improve upon our experiences.

During our everyday experiences, we are surrounded by different types of information. We can capture these varieties of information using different devices and sensors that are easily available these days. Self-submitted information by the individual and the information automatically collected from different devices & sensors together can help an individual to understand his/her experiences much more in detail.

The main objective of this thesis was to understand if the use of visualization and user-interaction techniques to visualize and interact with these types of user-related data support reflective learning in the user. To find the answer to this, an application was developed that can visualize user-related data as well as provide support for different interaction techniques to interact with these visualizations.

To find these visualization and interaction techniques for visualizing and interacting with the user-related data, at first, some scenarios were described where the user would collect data about themselves and would have questions related to their experience. Then the scenarios were analyzed using the CSRL (Computer Supported Reflective Learning) model. Different types of user-related data that can be collected (automatically by sensor or submitted by user consciously) were also categorized. And based on the scenarios, their analysis with CSRL model, and analysis of user-related data, high level requirements for the application were identified. These high level requirements, along with studying state of the art in visualization and user-interaction techniques, helped in identifying visualization and user-interactions techniques to be applied in the application. To make it easier for the users to collect data to be used in the application, another simple mobile application was also developed which can let the user collect data from themselves and from the user's environment. Both of these applications are open-sourced using the MIT license and are available online in GitHub repository.

The main application (VRL) was evaluated by the real users who interacted with the visualization of their own data. The results from the evaluation showed that visualization and user-interaction techniques can help user in their reflection process

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for the partial fulfillment of the requirements for a Master's degree. This work has been performed at the Department of Computer and Information Science (IDI), NTNU, Trondheim in the spring of 2015.

I would like to thank my Supervisor, Professor Monica Divitini, for her valuable feedbacks and guidance throughout the course of this thesis. I would also like to thank all the participants who volunteered to evaluate my application.

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Abbreviations

CSRL	:	Computer Supported Reflective Learning
MVC	:	Model View Controller
TEL	:	Technology Enhanced Learning
HCI	:	Human-Computer Interaction
InfoVis	:	Information Visualization
VRL	:	Visualize Reflect Learn
URL	:	Uniform Resource Locator
GPS	:	Global Positioning System
ADHD	:	Attention Deficit Hyperactivity Disorder
ESM	:	Experience Sampling Method
CAES	:	Context-Aware Experience Sampling
CASS	:	Contextual Activity Sampling System
ESM	:	Event Sampling Method
EMA	:	Ecological Momentary Assessment
IOT	:	Internet Of Things

1 Introduction

The main goal of this thesis is to understand if the use of visualization and interaction techniques for visualizing and interacting with user-related data also support reflective learning in the user.

This chapter describes the motivation, research questions and research method behind this thesis. Thesis structure is present at the end of this chapter.

1.1 Motivation

Reflection is the act of thinking about oneself and one's experience. Reflecting through the past experiences can allow us to learn from them, and this process is known as reflective learning [2]. Reflective learning can help us to form new knowledge from our experiences which will further help in the future.

Rapid advancement in mobile technology has made smart-phones and wearable devices very common these days. And because of steady progress in ubiquitous computing research, Internet of Things (IOT) [3, 4] is a very popular field now. Smart-phones, wearable devices and IOT devices, all are equipped with different types of sensors that can be used to collect different types of data [3-5]. This possibility has led to the realization of different applications for these devices.

A common aspect in all of these devices is that, their sensor can be used to collect data directly or indirectly related to the user. These sensors can collect data representing vital signs of the user like pulse rate, body temperature, respiration rate, etc., or data about the user's surrounding like temperature, noise level, etc. [6]. These types of data can help the user during the reflective learning process because, being directly or indirectly related to the user, they somehow also represent user's experience.

Data submitted by the user (through any medium) are the user's conscious inputs. These conscious inputs represent the user's interpretation of his/her experience at the time of submission, also popularly known as 'Experience Sampling Method' in research. These user-submitted data can help the user to reflect on his/her experience during reflective learning process.

Sensors can be used to automatically collect data about the user and/or the user's environment. User submitted data and sensor data relating to the user together can produce more

information. Correlation between these two types of data can help in understanding the user's experience in more detail [7].

When the data are represented visually as graphics or visual artifacts, the process of interpreting these artifacts is known as 'Information Visualization' [8]. In the field of technology, the term 'Information Visualization' has been widely used to mean the use of *computer-supported, interactive, visual representations of data to amplify cognition* [9]. Different visualization techniques has been in use for a long time and their use are even more increasing these day, and new ones are being researched more as it has been apparent that the proper visualizations can help us to grasp information more easily from the raw data than without.

Visualization alone is just a static graphical representation if we forget about the interaction methods [10]. Interaction allows us to interact with the representation or visualization providing the feeling of engagement with the data so that we can extract more information from them [11, 12].

1.2 Research Question

The main Research Question

● **Main RQ: Does the use of visualization and user-interaction techniques to visualize and interact with the user-related data (user-submitted data and sensor data related to user) promote reflective learning?**

This research question aims to understand if the use of visualization and user interaction techniques can be seen as a reliable approach that can be used for assisting reflective learning process when we have user-related data (user-submitted data and sensor data) at our disposal.

To help in answering the main research question, two sub research questions are defined

● **Sub RQ-1: Which visualization techniques are suitable for visualizing sensor data and user-submitted data?**

This research question is directed towards finding suitable visualization techniques to visualize sensor data and user-submitted data which would help in extracting more information from them.

● **Sub RQ-2: Which user interaction techniques provide good user experience for exploring and extracting information from data through the visualizations?**

This research question is related to Sub RQ-1 in the sense that it tries to identify the suitable user interaction techniques for interacting with the visualizations identified when answering Sub RQ-1. This research question aims to identify the user interaction techniques that can provide users with good user experience while allowing the user to easily explore the visualizations to extract more information from them.

1.3 Research Method

The research method I followed can be seen in several phases – Literature review, Problem Elaboration, Design & Implementation, and Evaluation.

In the initial phase, I conducted literature reviews of related topics. The literature reviews were mainly on the key topics 'Reflective Learning', 'Visualization' and 'User Interaction'. Similarly I researched on the similar works already done to what I am doing in this thesis. The most relevant literature reviews are presented in the 'Theoretical Background' chapter and similar works are presented in 'Related Works' chapter. With the end of the phase I had a clearer and deeper understanding of the topics.

After literature review, 'Problem Elaboration' was conducted in which the problem that the thesis is trying to solve was analyzed and described in detail. To do this I took an iterative approach by cycling back and forth with 'Literature Review' phase to understand related works that have already been done and which helped me in my analysis. During the 'Problem Elaboration' phase the problem was described using two scenarios, and based on these scenarios the need for development of two application was realized. Then the analysis of user-related data, identification of high-level requirements, and the requirement analysis were conducted.

At first, the design choices for each of the applications were made in the 'Design and Implementation' phase. Later, based on their respective designs, both the application were developed. At first the data collecting application 'VRL Data Collection' was developed which is intended to be a simple application to collect data for the main application 'VRL'.

After the development of the 'VRL Data Collection', the development of main application 'VRL' was done.

After the completion of the VRL application, it was evaluated in the 'Evaluation' phase by the real users. The progress of the thesis was documented in the report continuously from the start which was the final delivery along with the source code of application that were developed.
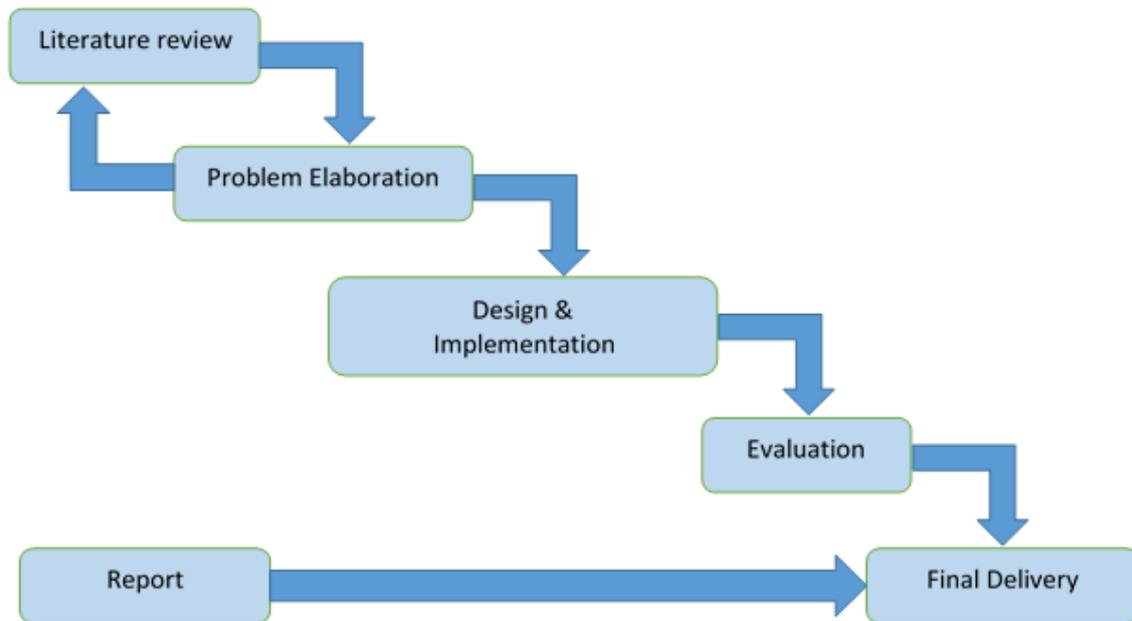
Figure 1 Research Approach taken in this thesis

1.4 Research Domain

This thesis is focused on the intersection between Technology Enhanced Learning (TEL), Information Visualization and Human Computer Interaction. The research domain for this thesis is shown in the figure 2.
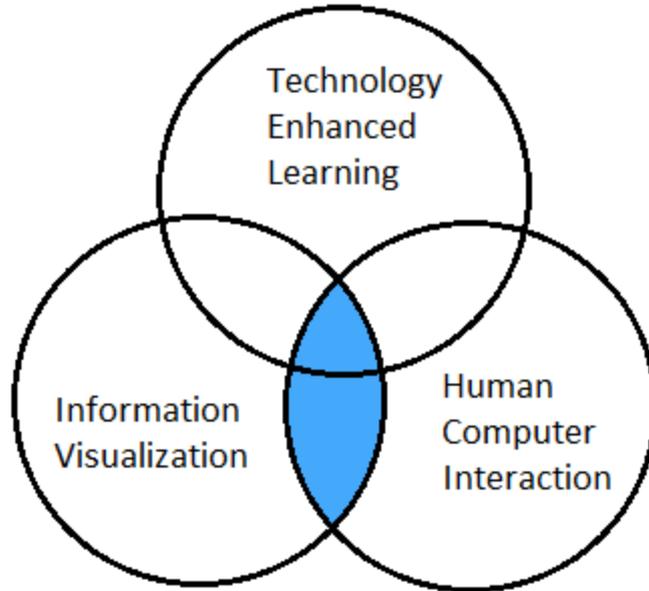
Figure 2 The research domain

1.4.1 Technology Enhanced Learning

Technology Enhanced Learning (TEL) refers to the use of technology for supporting learning. With computers being ubiquitous and present in all different forms, they are increasingly being used to assist learning activities, and results have been very optimistic.

In the context of this thesis, CSRL (Computer Supported Reflective Learning) model would be the basis for developing the application to support reflective learning, and thus this application would also be the contribution towards this domain.

1.4.2 Information Visualization

Information visualization (InfoVis) is the set of technologies that present data in the visual form to amplify cognition [13]. InfoVis deals with providing the user with computer generated visual artifacts based on the data they provide, and allowing the user to interact with them for exploring and understanding them further. There has been a large volume of works done towards building different InfoVis systems, techniques and strategies for visualizing data.

In the context of this thesis, it makes use of some of the well-known visualization techniques for visualizing the user-related data. And also presents the evaluation of few innovations towards visualization done as part of this thesis.

1.4.3 Human-Computer Interaction

Human-Computer Interaction (HCI) deals with researching, designing and developing human-centric computer technologies. HCI concentrates on how human interacts with computer, and focuses on how the interfaces between humans and computers be improved. HCI, in itself, is a big field in computer science that has intersection with many other different other fields, mainly behavioral science and design.

Interaction and visualization is the part of the topic of this thesis, and so the domain intersecting InfoVis and HCI is of the interest to this thesis. Application developed under this thesis takes interaction as a medium for the users to interact with their data, and so the theories behind them fall under both InfoVis and HCI domain.

1.5 Results

Going through the design, development and evaluation of visualization & interaction based application for reflective learning, one of the results of this thesis can be the increased understanding of the role of visualization and interaction in reflective learning. Evaluation of the application and positive results contribute towards the confirmation that the use of visualization and interaction can somehow contribute to reflective learning.

Novel approach to visualizing ordinal data based on the order itself (ordinal placement of ordinal values), and visualizing continuous data & user-submitted data in a same chart for finding correlation between them can be taken as the contributions to visualization domain. These visualization techniques were previously conceptualized in the Autumn Project but they were implemented and evaluated in this thesis.

Two applications, namely 'VRL Data Collection' and 'VRL' can also be seen as the result of the thesis. 'VRL Data Collection' application is for collecting user related data (user-submitted data along with sensor data related to the user) and 'VRL' application is to

visualize them. 'VRL' application allows a user to look at user-related data through different visualization and interaction techniques that would help the user in understanding his/her experience better and help in their reflective learning process.

Both the application are open-sourced with MIT license[14] and are available in the online GitHub repository.

Table 1 URL for source code of applications developed under this thesis

Application	URL
VRL application	`https://github.com/pawanchamling/VRL-App`
VRL Data Collection application	`https://github.com/pawanchamling/VRL_Data_Collection`

1.6 Previous work – Autumn Project

This thesis has utilized some of the concepts developed in the project delivered in the course TDT4501 Computer Science, Specialization Project in autumn 2014 [15]. The result of the Autumn Project was a guideline for choosing visualization techniques for different types of WATCHiT data. The types of data WATCHiT is capable of collecting resembles user-related data that this thesis is focusing on, so analysis of WATCHiT data was helpful for doing the analysis of user-related data in this thesis. Approach to visualizing the correlation between continuous and ordinal/nominal data explained in the 'Autumn Project' has been used in this thesis. Similarly, the ordinal placement of ordinal values visualization technique explained in the 'Autumn Project' has also been used in the thesis.

1.7 Thesis Structure

This section describes the organization of the rest of the chapters in this thesis.

Chapter 2: Theoretical Background: Describes the theoretical background behind the thesis: Reflective learning and CSRL model.

Chapter 3: Problem Elaboration: Further elaborates on the problem this thesis is set out to answer by presenting some scenarios, analyzing these scenarios & different type of user-related data, and finding high-level requirements for the application that is to be developed

Chapter 4: Related Works: Explains the related works that have been done in the field of Quantified self, Information Visualization and Interaction, and Reflective Learning that are related to the work this thesis is set out to answer

Chapter 5: Design & Implementation: Explains the design choices and implementation of the applications

Chapter 6: Evaluation: Describes the evaluation of the application, and also presents the discussion on the results and if they answer the research questions

Chapter 7: Conclusion: Presents the summary of the thesis and future works that can be done based on this thesis.

2 Theoretical Background

This chapter presents the theoretical background for this thesis. This includes information on Reflective Learning and Computer Supported Reflective Learning.

2.1 Reflective Learning

We, as human beings, reflect upon our past experiences time and again. Reflection, to us, is as natural as thinking. Dewey [16] explained that reflection is a special part of our thoughts which is rational, purposeful and conscious. We reflect upon our past experience to understand or uncover something which we are not already aware of. So reflection is exploratory in nature [2]. The act of reflection always has some form of outcome [17] and the outcomes may not be as expected [2] but the outcomes are always some form of learning.

Boud et al. [2] defined reflective learning as

"…those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understanding and appreciations."

According to Moon [18],

"Reflection is part of learning and thinking. We reflect in order to learn something, or we learn as a result of reflecting, and the term 'reflective learning' emphasis the intention to learn from current or prior experience."

So reflective learning leads to insights that can help an individual into improving his/her future experiences. In the work context, the act or practice of reflection is the person's intention to make sense of and to learn from the work experiences in order to achieve more desirable, effective and satisfying work [19]. Wilkinson [20] referred this reflective practice at work place as "an active process whereby the professional can gain an understanding of how historical, social, cultural, cognitive and personal experiences have contributed to professional knowledge acquisition and practice."

2.1.1 Kolb's Cycle

David Kolb defined a four stage cycle popularly known as Kolb's cycle or Kolb's experiential learning cycle. The four stages in Kolb's cycle represent the different stages a learner reaches

in the process of learning from an experience. Reflection is one of the stages of the cycle that comes after the concrete experience and which leads to abstract concepts and conclusions. By re-evaluating the past experience, reflection leads to new concepts or some modification of existing abstract concepts which the learner can apply or experiment in the similar situations [21]. A complete cycle is formed after the experimentation, which leads to newer concrete experiences. The cycle can go on allowing the person to build newer experiences and knowledge helping in his/her continuous development.
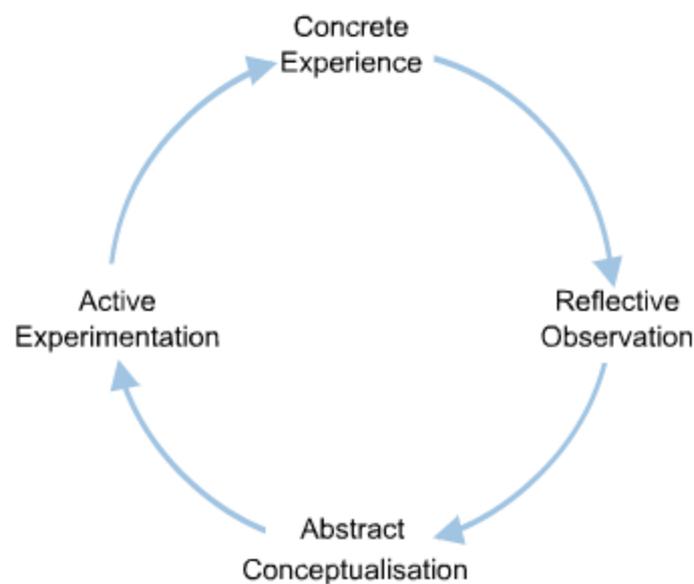
Figure 3 Kolb's Experiential Learning Cycle

According to Kolb [22], learning or the learning cycle is an integrated process where each of the stages are interdependent with each other, where each stage gets support from the previous stage and which, in turn, supports the next stage. It is possible to enter into the cycle from any of the stages and continue sequentially to complete the cycle.

Through Kolb's cycle we can clearly see how important reflection is in any form of experiential learning. We can say that experiential learning isn't possible without reflection as reflection is the part of such kind of learning.

2.1.2 Schön's Model

Donald Schön's take on reflection is centered upon defining it as a tool for personal or professional development. He described reflection as a form of activity done for the purpose of unraveling knowledge in order to become more knowledgeable, skillful or expert in the topic [23]. He also pointed out that reflection can also work as a corrective measure to over-learning, where a person can re-examine his/her understandings, criticize them and make a new sense out of them [23]. He categorized reflection into two categories based on context and time: 'reflection-in-action' and 'reflection-on-action'.

Reflection-in-action refers to reflecting on the very action that is being performed for the purpose of monitoring it. This type of reflection is triggered by the unexpected surprise, whether positive or negative, which is capable of capturing our attention. Whether the things are going right or wrong, when we are surprised and our attention is captured, we would start reflecting on it. This type of reflection is called reflection-in-action. Reflection-in-action leads to awareness about our current actions and results into planning for the next actions. While we are still performing, reflection-in-action helps us to take a new course of actions based on the judgement we reach after reflecting on our current course.

Reflection-on-action refers to reflecting on the actions that have been performed some time earlier. According to Schön's, reflection-on-action is the retrospective analysis of experience performed for the sole purpose of improving upon skills and knowledge, or for getting expert in the topic [23]. Through reflection-in-action we are reflecting upon our past actions, trying to analyze them and come up with some knowledge about them that can be applied in similar situations. So reflection-in-action allows us to improve or be prepared for the similar future experiences.

2.1.3 Reflective Learning Model by Boud et al.
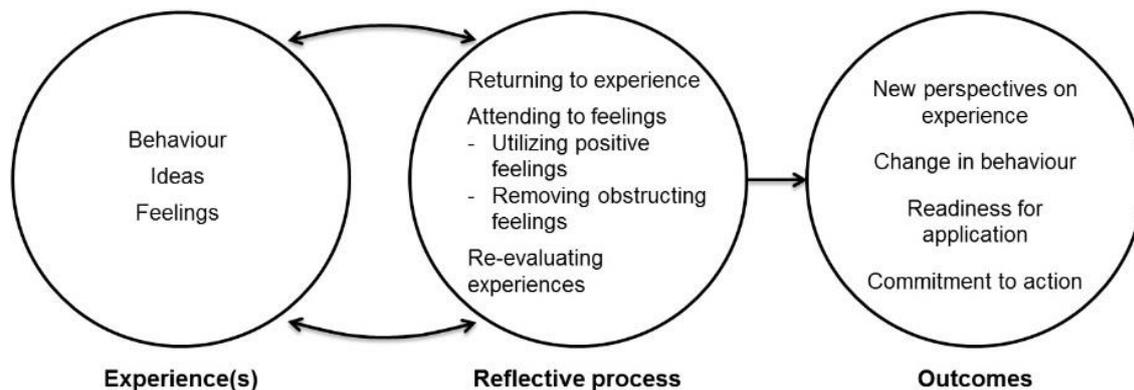
Figure 4 Model of Reflective Learning. From Boud et al. (1985) [2]

In 1985, Boud, Keogh and Walker developed a three component model of reflective learning [2]. The three components of the model are 'Experience(s)', 'Reflective Process' and 'Outcomes'. 'Experience(s)' represents all the things that make up the experiences of the learner. These things could also include the behaviors that the learner have engaged before, ideas the learner possess and the feelings that the learner have experienced [2].

'Reflective Process' represents different stages which the learner goes through during the reflection process. First, the learner will return to the experiences or events trying to recall in as much detail as possible. Then the learner will have to consider those experiences or events in emotional as well as cognitive level utilizing the positive feelings and removing the obstructing ones. When the user will have acquired new knowledge, the learner will have to re-evaluate the experience by relating this new knowledge with the previous experiences and knowledge, and try to find more meanings or understandings from them. At the end of the re-evaluation, the learner will integrate this new knowledge into the existing conceptual framework.

'Outcomes' would be the results of the reflection process. They could be the new perspectives towards the experiences, behavioral changes, or readiness for applying the new knowledge on new experiences.

The model explains the reflective learning to be an iterative process, and not the sequential one, where the 'Reflective process' and 'Experiences' can cycle around iteratively many times before the outcome is realized or achieved.

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2.2 Computer Supported Reflective Learning

To support reflective learning in people, different computer based tools have been researched and developed, and they were also found to be effective in it [24-26]. To support developing computer tools for the purpose of reflective learning, Computer Supported Reflective Learning (CSRL) has been proposed which intends to serve as a framework for understanding, analyzing and supporting reflective learning process in the workplace context [27]. CSRL model is theoretically based and built upon reflective learning model by Boud et al. and aims to support both individual and collaborative reflections.

CSRL model considers reflective learning process as a four-staged cycle. Each of the stages gives out something as an output which would serve as an input to the next stage. And there could be a reflection trigger being generated in any of the stages that could start a new reflection cycle.
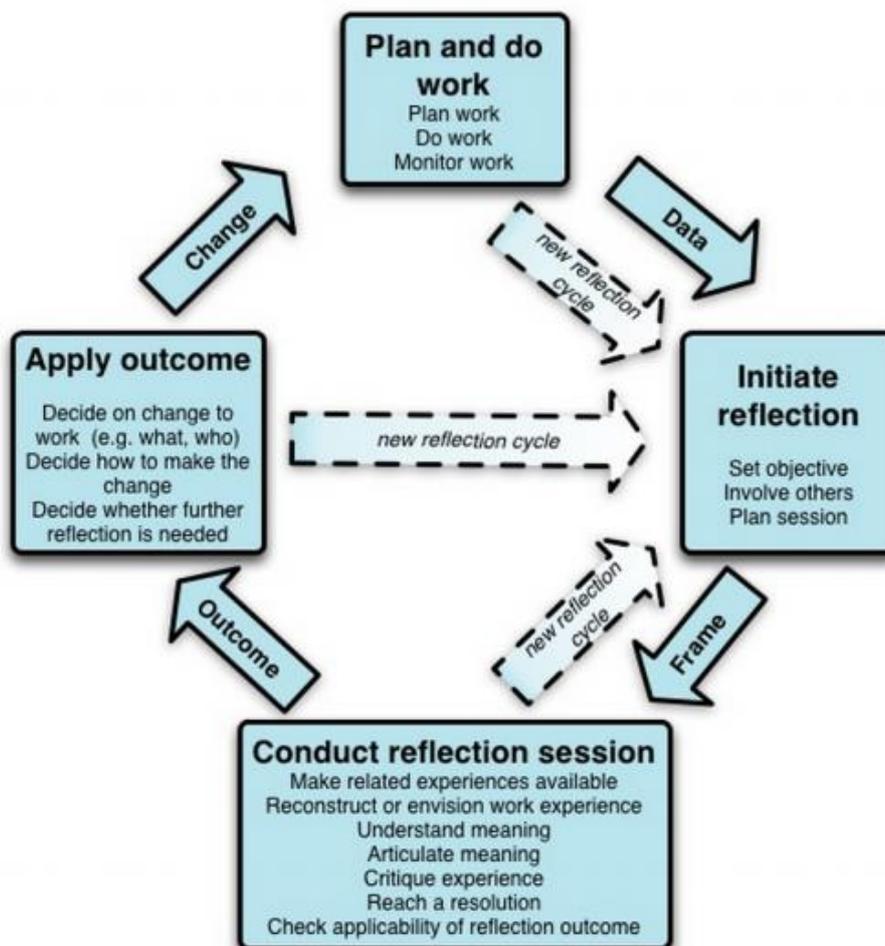
Figure 5 The CSRL Model. From Krogstie et al. (2013) [27]

The four stages of CSRL model are

i. Plan and do work

In this stage, the actual work or activity is performed. Different activities done in this stage are planning the work, conducting the work and monitoring the work. The output of this stage is 'data' representing the experience of doing the work which can be used in the reflection session.

Table 2 'Plan and do work' stage of the CSRL model [27]

Plan and do work	
Input: Change	
Output: Data, Reflection trigger	
Plan work	The particular kind of work that involves planning other work
Do work	Conduct work tasks
Monitor work	Observe the state of the work. This includes the individual's self-monitoring during work and external monitoring

ii. Initiate reflection

This is the stage that represent the time when the learner decides to reflect on the experiences. This stage represents the start of the reflection session and can be reached by any other stages if some incident generates a reflection trigger. In this stage, the objective and plan for the reflection session is set, involving related people if there is any. The output of this stage is a 'Frame' for the actual reflection session, here *Conduct reflection session* stage.

Table 3 'Initiate reflection' stage of the CSRL model [27]

Initiate reflection	
Input: Reflection trigger, Data	
Output: Frame for the reflection session	
Set objective	Set the objective for the reflection on the basis of the reason why reflection was triggered
Involve others	Involve others if needed (based on the reason why reflection was triggered)
Plan session	Plan the session by determining the time, place and approach

iii. Conduct reflection session

This is the stage where the actual reflection occurs. The reflection session is constrained by the frame generated in the *Initial reflection* stage. Here in this stage, the learning takes place when the previous experience are reflected upon. Each of the reflection session has a topic of reflection, an objective, a certain time allocated for the reflection session, one or more participants involved and an 'outcome' which would be input for the *Apply reflection outcome* stage.

Table 4 'Conduct reflection session' stage of the CSRL model [27]

Conduct reflection session	
Input: Reflection frame	
Output: Reflection outcome, Reflection trigger	
Make related experiences available	Make available and share work experiences relevant to address the reflection objective
Reconstruct or envision work experience	Reconstruct relevant work or envision them as future experience
Understand meaning	Relate experience to relevant context (in the light of the reflection topic)
Articulate meaning	Formulate the meaning in a way that makes it understandable to others
Critique experience	Critically evaluate the experience by use of relevant criteria
Reach a resolution	Agree on – or decide when there is – satisfactory outcome of the session; formulate the outcome
Plan to apply reflection outcome	Clarify whether and how the outcome can be applied in practice

iv. Apply reflection outcome

This stage represents the time when the results or outputs from the reflection session are realized as the knowledge and based on which the decision on what to change is done. This stage involves activities like deciding on what to change, how to make those changes, and deciding on if more reflection is to be done. The results of this stage can be the changes on the actual or input to a new reflection cycle, or both.

Table 5 'Apply reflection outcome' stage of the CSRL model [27]

Apply outcome	
Input: Reflection outcome	
Output: Change; Reflection trigger	
Decide on change to work (e.g. what, who)	Finding out what change on the work arena should be made, and who will be involved
Decide how to make the change	Considerations may involve whether a change to work can immediately be mad and/or whether it should be described and shared, informally or formally
Decide whether reflection is needed	It may be that the participants see a need for change but cannot identify or agree on a solution, or that there is a need for the involvement of other with more expertise or power. These may be reasons to initiate a new reflection cycle.

3 Problem Elaboration

In this chapter, the problem that the thesis is going to answer is elaborated further.

3.1 Scenarios

I have identified few scenarios through which the problem that the work here is trying to address can be clarified more.

3.1.1 Scenario 1

A student is writing his thesis (or preparing for examinations) and has set a certain fixed amount of time to work on it every day. He takes breaks frequently and does different activities like going out for a walk, listening to music, etc. He wants to track his productivity throughout the working hours and is interested in knowing if environmental noise and/or temperature is influencing his productivity. He also wants to know the pattern for his productivity in a normal day and what types of activities he indulges himself during the breaks. He has a smartphone with which he can keep notes and also which is capable of recording ambient noise, ambient temperature and GPS location.

3.1.2 Scenario 2

A person has a full time job which is stressful at times. He has to do a lot of meetings and even travelling sometimes during the work. He is concerned about his health and wants to stay active but less stressed during the work. He wants to understand when his stress level rises and when it is normal and if they are influenced by the location and/or type of the work. He also wants to know his energy level during the working day and see the correlation with the stress level and/or with the surrounding temperature. He owns a fitness band that can record his heart-rate and activity level. He also owns a smartphone through which he can keep notes and record his GPS location. And also he has access to the data about his workplace's ambient temperature.

3.2 Problem Definition

In the previous section, two scenarios were explained through which we can understand the problem more clearly. As we can see that in both the scenarios, the users had some devices to record data about (or related to) themselves. Through those devices a user can submit data himself/herself, the devices can collect data themselves, or both. But the collected data in itself does not serve the user much as the user would have a hard time extracting much information from them. There needs to be some mechanism to utilize those data so that the user can take benefit from them and help him/her answer his/her questions.

The term 'Visualization' has been commonly used to mean the use of graphical representations for the purpose of communicating information [28]. Visualization can help us make sense out of data by transforming data into visual form which would make it possible for us to discover patterns, trends and hidden characteristics from them [29]. And it is already known that we are much more efficient in processing and interpreting visual diagrams than that of words [30] or raw data [31], so employing visualization technique can help us easily extract information from the data.

For a user, visualizing the data related to oneself and one's own experience, it may become easier to mentally re-create the experience. This may allow the user to reflect on the experience, examine his/her own behaviors during the experience, and maybe also learn something from it. And if the visualization presents the user something surprising or inconsistent to what s/he believes, it results to a mental discomfort known as 'Cognitive dissonance'[32] which further will trigger reflection [33]. And since it has been found that visualization can assist in reflective learning [34, 35], appropriate visualization techniques needs to be identified and applied to support reflective learning.

Interaction techniques are also very important because without them the visualization would only be static representations and because of which the user won't have options to extract more information from them. By interacting and even changing the representation, a user can extract more information from these visualization using different interaction techniques.

So, in order to answer the research questions, an application that is capable of visualizing the user-related data would be developed. The application would be designed focusing on the visualization and user interaction techniques keeping reflective learning as the ultimate goal. Hence, the application would be called VRL (Visualize Reflect Learn). The VRL application

would not be a solution to a specific problem but rather a generic solution to all the scenarios where there would be the presence of user-related data.

Since the user-related data can be of different types and would have many sources, and usually they would be found in different data formats (or data-interchange formats or file formats), the VRL application obviously would not be able to support all of them. This issue of data coming from various sources in heterogeneous form and format has also been found to be a common issue among life-logging systems [36]. To tackle this problem, VRL application would define its own data format for all the different types of data it needs to support so that the data from the different sources can be converted to this format to be used in the application.

Another application would also be developed for the purpose of collecting some user-related data in the format that the VRL application would support. This data collection application, namely 'VRL Data Collection' application, would not be directly related to answering any research questions, but rather just to assist in collecting suitable data which can be used by the VRL application. Nowadays almost everyone owns a mobile device and carries it around with them, the 'VRL Data Collection' application would be a mobile application so that users would always have access to it, and the application can take benefit of collecting data from the mobile device's inbuilt sensors. The 'VRL Data Collection' would also allow the users to collect ordinal and nominal types of values.

In order to use data from different sources, different data format conversion plugins or features should be built onto the VRL application, which may take a lot of work. Since the main focus of the application would be in visualizing user-related data for the purpose of reflective learning, the decision on developing 'VRL Data Collection' application was taken to avoid spending much time on supporting multiple data formats but instead to use an alternative and quicker solution.

3.3 Modified Scenarios

The scenarios presented before would be modified to explain how the two applications that would be developed can come to use in those scenarios.

3.3.1 Scenario 1

A student is writing his thesis (or preparing for examinations) and has set a certain fixed amount of time to work on it every day. He takes breaks frequently and does different activities like going out for a walk, listening to music, etc.

He uses the 'VRL Data collection' application in his smartphone to enter ordinal and nominal notes throughout the work day. He uses ordinal values like "Very productive", "Productive", "Not Productive" to record his feeling of the degree of being productive in every half an hour interval. He also puts some message/note along with the ordinal value to note down about the activities and/or feelings at the moment. Through the 'VRL Data collection' application, he also records the ambient noise, ambient temperature and GPS data throughout the day.

At the end of the day, he wants to understand his day through the data he collected. He wants to know the pattern of his feeling of productivity for that day. He also wants to know if there is any correlation between his productivity and the noise around him. Similarly he also wants to know if there is any correlation between his productivity and temperature of his workplace. He wants to know if the location was influencing any of his behaviors or emotions.

So he uses the ambient noise data, ambient temperature data, GPS data, nominal data and ordinal data collected from the 'VRL Data collection' application into the VRL application. Through the VRL application he visualizes the correlation between these different data. He uses different interaction techniques to explore his data. To focus on the data of his choice, he would load/unload or show/hide the data of his choice during the process. This way the student will get to reflect on his experience and figure out if there is any correlation between his productivity and the noise around him and/or the location of the place, etc.

3.3.2 Scenario 2

A person has a full time job which is stressful at times. He has to do a lot of meetings and even travelling sometimes during the work. He is concerned about his health and wants to stay active but less stressed during the work. He uses the 'VRL Data collection' application to collect ordinal values representing the feeling of being energetic like "Very energetic", "Energetic", or "Not very energetic". He also uses the 'VRL Data collection' application to note down nominal messages about the different activities he is doing during the work, like

"having breakfast", "travelling to work", "attending meeting", "out on lunch", etc. He also uses the application to collect ambient temperature and GPS data. He uses the fitness band to collect heart-rate and activity level related data.

At the end of the day, he wants to understand when his stress level rises and when it is normal and if they are influenced by the location and/or type of the work. He also wants to know his energy level during the working day and see the correlation with the stress level and/or with the surrounding temperature. He wants to know the most active part of the day and also the most stressful time of the day.

So he uses the collected data (GPS data, ambient temperature, nominal data, ordinal data, heart-rate data, and activity level data) and loads them into the VRL application to visualize them and reflect on his experience that day. He uses different interaction techniques to scrutinize the data and try to find the answers to his questions.

3.4 Analysis of user-related data

The main objective of the thesis is to find out if the use of visualization and user-interaction techniques for visualizing and interacting with the user-related data promotes reflective learning in the user. And the other objective is finding out appropriate visualization and interaction techniques for these data. Based on the sources of data that we are going to visualize and interact on, the user-related data can be categorized into two main categories:

 i.   User-submitted data
 ii.   Sensor data

3.4.1 User-submitted Data

User-submitted data refers to all those data that a user can submit by himself/herself consciously. A user can submit qualitative types of data which can be nominal or ordinal in nature. Looking at the scenario 1, we can see that the ordinal data could be related to productivity like 'Very productive', 'Productive', 'Not Productive', etc. and nominal data could be about the users note like "taking a break", "going out for a walk", "feeling lazy", etc. which represents the user's feeling and activities at the time of submission. If these qualitative

data are represented in quantities or quantitatively, then they can be seen as 'discrete data', like the amounts of time the 'Very productive' ordinal value was entered, etc.

Table 6 User-submitted data in each of the identified scenarios

User-submitted data		Scenarios	
		Scenario 1	Scenario 2
Qualitative Data	Ordinal data	e.g. feeling of productivity "Highly Productive", "Productive", "Not Productive"	e.g. feeling of being energetic or active "Very energetic", "Energetic" "Not very Energetic"
	Nominal data	Notes like "taking a break", "having a lunch", "going out for a walk", "feeling lazy", etc.	Notes like "travelling to work", "attending meeting", "out on lunch", "feeling stressed", etc.
Quantitative	Discrete data	e.g. frequency of each of the nominal or ordinal value	e.g. frequency of each of the nominal or ordinal value

User-submitted nominal data can take other forms that are not just simple texts, like voice/sound clip, video clip, photo/pictures from camera, etc. For the convenience and not to complicate the process, nominal data are taken to be text data in the thesis.

3.4.2 Sensor data

Sensor data refers to all those data collected automatically by a sensor. The types of data collected by the sensors can again be categorized into two types, one being the data related to the user's context or environment like the temperature, noise level, humidity, air purity, etc. and the other being the data related to the user's vital signs like user's body temperature, heart rate, blood-sugar level, etc. In the scenario 2, heart-rate data and activity-rate data represents data about user's vital signs and workplace ambient temperature data represents data about user's environment. Both of these two types of data would be quantitative in nature. Environment related data can also be of two types, either geo-location type or simply continuous data.

Table 7 Sensor data in each of the identified scenarios

Sensor data	Quantitative data	Scenarios	
		Scenario 1	Scenario 2
User's vital signs related data	Continuous data	-	Heart rate data, Activity level data
User's environment related data	Continuous data	Ambient noise data, Ambient temperature data	Ambient temperature data
	Geo-location data	GPS data	GPS data
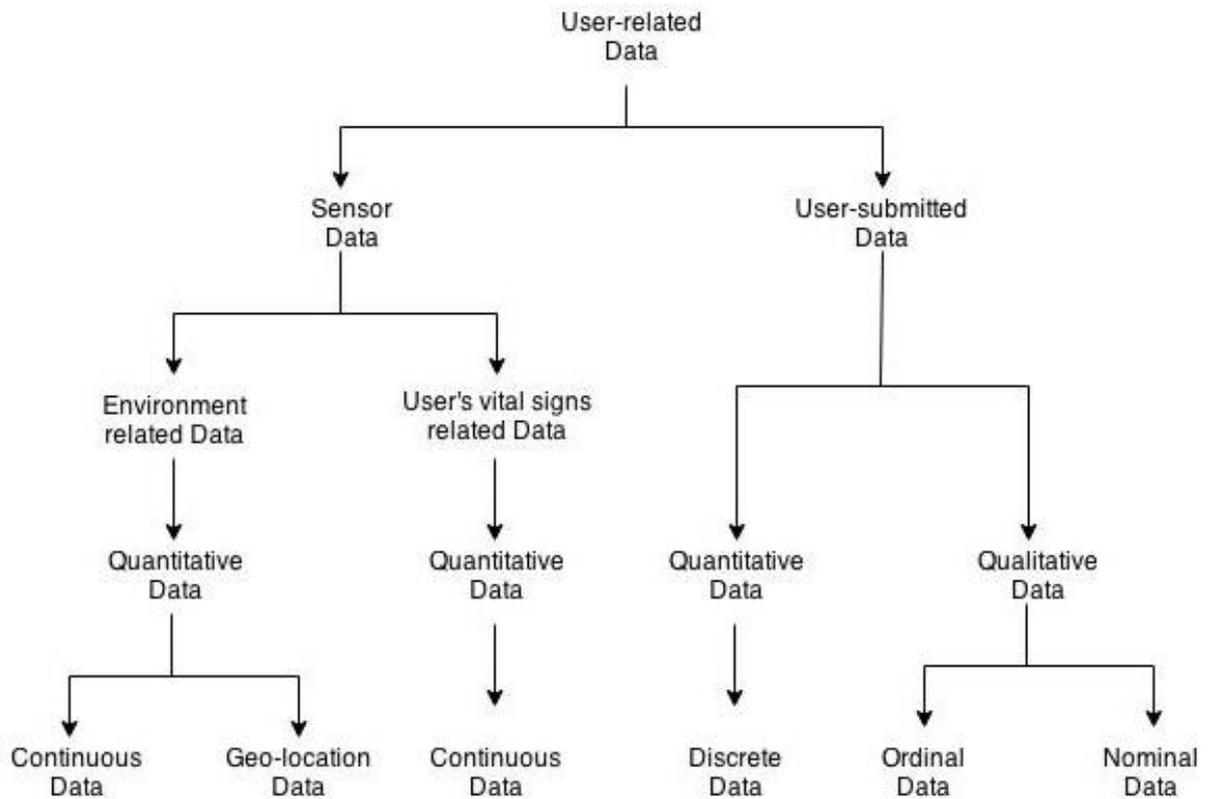
Figure 6 Categorization of User-related data

Looking at the identified different categories of data, we can see that we have mainly five categories of data.

    i.   Geo-location data

    ii.   Continuous data

    iii.   Discrete data

    iv.   Ordinal data

    v.   Nominal data

3.5 Analysis of Scenarios with CSRL Model

In this section, the scenarios previously defined would be analyzed with the CSRL Model. The 'VRL Data Collection' application is used for collecting data during the actual experience, so it would be related to 'Plan and do work'. The main application i.e. VRL application is used for visualizing different data collected by different means, so 'Initiate Reflection' and 'Conduct Reflection Session' stages of CSRL Model will be relevant for the application.

Plan and do work

The use of mobile device (smartphone) or wearable devices to record data, and planning to use (or setting up) ordinal values can be seen as the *Plan work* activity. Using those ordinal values during the work and writing notes (nominal values) can be seen as the *Do work* activity. These self-submitted data and data automatically collected by different devices would be the 'Data' used by the 'Initiate Reflection' stage.

Table 8 'Plan and do work' stage

Plan and do work	
Input: -	
Output: Data collected by VRL Data Collection application	
Plan work	- Planning to record data through the VRL Data Collection application, - Setting up the appropriate ordinal values in the VRL Data Collection application to be used during the work
Do work	- Entering nominal notes into the VRL Data Collection application

	- Using the ordinal notes previously configured in the VRL Data Collection application
Monitor work	- The VRL Data Collection application collects the sensor data using the mobile device's sensors

Initiate Reflection

Loading different types of data into the VRL application can be seen as the *Set objective* activity. Removing data that had been previously added, and customizing the look and feel of the loaded data or filtering them to focus on only some portion can also be seen as the part of 'Initiate Reflection' stage. These loading, removing and preparing data can be seen as the *Framing* of reflection session for the 'Conduct Reflection Session' stage. At the end of the day, planning to use the data collected from the VRL Data Collection application into the VRL application can be seen as *Plan session* activity.

Table 9 'Initiate reflection' stage

Initiate reflection	
Input: Data from the VRL Data Collection Application and other sources, Reflection trigger Output: Frame for the reflection session	
Set objective	- Loading data - Removing data - Customizing data
Plan session	- After enough data is collected by the VRL Data Collection application (usually at the end of the day), the plan to use these data into the VRL application

Conduct Reflection Session

In the 'Conduct Reflection Session', the visualization in the application would help the user to reconstruct his/her experience. The user would be able to understand how the data presents his/her experience and see if they are consistent to what s/he has been believing them to be. The user would be able to use the different user-interaction techniques to explore and scrutinize the data for understanding and for comparing them. Any inconsistency or surprising information will create a 'reflection trigger' which would take the user to the 'Initiate reflection' stage and start a new reflection cycle. When such event occurs, the user would be

interested in filtering or focusing on the part of data that is representing such inconsistencies or surprising information, this can be seen as the triggering of new reflection cycle and going back to the 'Initiate reflection' stage.

Table 10 'Conduct reflection session' stage

Conduct reflection session	
Input: Reflection frame Output: Reflection outcome, Reflection trigger	
Make related experiences available	- Adding more data during the reflection session The user can add more data into the application during the reflection session to equip the reflection session with more data about the experience.
Reconstruct or envision work experience	- User's experience as the Visualizations in the application User's experience would be visualized based on the different user-related data that are loaded into the VRL application. The visualizations would represent the user's experience.
Understand meaning	- Visualization of contextual data (sensor data related to user) and the user-submitted data help the user in understanding and comparing it with what s/he remembers about the experience - Using interaction techniques to extract more information from these visualization to understand the experience more. The user can understand the experience more by comparing the experience that the user remembers with how the data represents it through visualization in the application. The user can also interact with the visualizations using different interaction techniques to explore the data so as to extract more information from them, and to understand what they tell about their experience.

3.6 High Level Requirements

This section will describe the high level requirements for the main application i.e. VRL application as it is the one through which the research questions are going to be addressed. Based on the types of data analyzed in previous section and analyzing the scenarios previously described, we can identify high level requirements for the application.

3.6.1 Support for different types of data

The main objective of the application is to promote reflective learning in the user through the data directly or indirectly related to him/her. As we noticed from the scenarios that there could be different types of data related to the user, data either submitted by the users themselves consciously and/or data automatically collected through the sensors of the devices. So the application should be able to support these different types of data to visualize them for the user. Looking at the analysis of user-related data done before, the different types of data the application needs to support can be

  i.   User-submitted nominal data
  ii.   User-submitted ordinal data
  iii. Continuous data automatically collected by the sensor
  iv.   Geo-location data automatically collected by the sensor

Since the discrete data are derived from user-submitted data i.e. they are the quantitative representations or frequencies of nominal and/or ordinal values, discrete data are not taken as inputs for the application but rather something the application should calculate or process itself. Thus, discrete values are expected to be the outputs of the application rather than being inputs to the application, so it has been omitted from the list above.

3.6.1.1 Data format

As discussed in the problem definition section and seen through the scenarios, the user-related data can be collect from different types of devices and each of these data sources will have their own data format (or data-interchange format or file-format) for storing or transferring the data. Since the main application (VRL) requires to support different types of data coming from diverse sources, the application must be able to understand the format of the data to load them. To develop an application that can readily support data of different formats can be a lot

of work. Instead, defining our own data format to which other formats can be converted seems much easier as the data-format conversion features (to convert other formats into the application's data format) can be gradually added onto the application to support these diverse data-formats. So a requirement of the application can be selecting or defining a data format for each of the different types of data it needs to support.

3.6.2 Proper Visualization and Interaction techniques

As we noticed from the scenarios and the analysis of the user-related data, the application needs to visualize different types of data. It may not be possible or it may not be appropriate to visualize all of these data with the same technique because each of these different types of data have their own unique properties. For illustration, a GPS data (Geo-location data) cannot be visualized the same way as a noise data (Continuous data) because it wouldn't make any sense to do so, and if deliberately attempted, no proper information can be extracted from that. Similarly, to find the correlation between different types of data we may need to find a proper way to visualize them. So a requirement for the application would be to have visualization techniques appropriate for each of the different types of data and/or their combinations so that the user can easily understand them and extract information from them.

The application must also provide the intuitive interaction techniques for the user to explore the data through the selected visualizations.

3.6.3 Support reflection: Revisit experiences through visualization

Since the main target of the application is to foster reflective learning in the user, supporting reflection is one of the main requirement of the application. The application is taking the visualization and user-interaction approach to support reflection, so the decisions on choosing these techniques should be influenced by how they would support the users in revisiting their experiences.

Boud et al. [2] has described reflection as *an important human activity in which people recapture their experience, think about it, mull it over and evaluate it.* And looking at the analysis of scenario with CSRL model in the previous section, we can see that the 'Conduct Reflection Session' stage is where the application can help the user to make *the related*

experiences available, reconstruct or envision the work experience and *understand meaning*. So the selection of visualization and interaction techniques focusing on these activities would ensure that they would support reflection in the user.

3.6.4 Good User-Experience/Usability

The application would need to support different types of data and proper techniques for visualizing them. But the main objective of the application is to promote reflective learning in the user, and so, the user also needs to have a good experience while using the application. So one of the requirements for the application would be to possess a user-friendly user interface along with intuitive interaction techniques.

3.7 Visualization and Interaction Challenges

This section describes the different visualization and interaction challenges that the application needs to address, and then the analysis of these challenges.

3.7.1 Challenges

Based on the scenarios and analysis of user-related data previously presented, here are some of the visualization and interaction challenges identified.

3.7.1.1 Correlation among data

As the high level requirement '*support for different types of data*', we have identified that we have four categories of data for the application to visualize. For each of these different categories of data there are established and popular visualization techniques already identified.

Table 11 Data types and common visualization techniques

Data	Common Visualization techniques
Continuous time-series data	- Using line chart [37, 38] - Using area chart [39] - Using bar/column chart [40], etc.

Geo-location data	- Maps
Nominal data	- Textually - Icons/shapes/symbols [41] - Bar/column chart [42] (when realized as discrete value)
Ordinal data	- Textually - Icons/shapes/symbols [41] - Bar/column chart [42] (when realized as discrete value)

But the challenge here is when we have to visualize these different types of data together to understand if there is any correlation between them. There are many works done towards using or finding visualization techniques to see the correlation among the same type of data but not among the different types of data. So we have a visualization challenge of finding a visualization solution to allow exploring the correlation between different types of data. This challenge can be directly related to the high level requirements of finding *proper visualization and interaction techniques* and *supporting reflection*.

3.7.1.2 Filtering/Focusing

As seen from the analysis of user-related data and the scenarios, a user could be collecting different types of data during their actual experience. When these data are loaded into the VRL application, all of these data would be visualized. But at any point in time when the user is looking at the visualization, the user may want to look only at a data or few of the data, but not all at once. The user may want to focus on only the ones that s/he is interested in, which will make the reflecting back to experience much easier. Like in scenario 1, the student may want to look only at the ordinal data and noise data while trying to see correlation between them. While reflecting on the use of ordinal data and how noisy the environment was, the user can compare them easily with what the data represent visually. There is no need for the student to see nominal and location data and so s/he may want to filter them out. Having all the data visualized at once may also cause visual clutter because of which the user may find it hard to make sense out of data.

Similarly, when all the data collected during the actual experience are visualize at once, the user would have the complete overview of his/her entire experience. But the user may want to focus only on the certain time-periods of his/her experience and not the entire experience as a

whole. Like in scenario 1, the student may want see the visualization of only the last hour of his experience or the time-period which he felt the most productive. The user would need a mechanism to filter/focus his/her data.

During the selection of visualization techniques for the user related data, we also need to consider this filtering/focusing challenge. Filtering/focusing is directly related to high level requirements of finding *proper visualization and interaction techniques* and *supporting reflection*.

3.7.1.3 Different levels of detail/Details on demand

Some of the types of data like continuous data from sensors may contain a lot of data points within a small time-frame. Visualizing all of them is possible but because of too many data points, the whole visualization may look cramped with lot of figures and may obscure the visualization itself. There would be the issue of viewability or usability as it will become very difficult to distinguish between nodes and edges [43]. The challenge is to make it possible to view the data in different levels of detail so that the details can be obtained when the user wants it. Like in scenario 1, the user is collecting noise and temperature data and if these data are collected every 30 seconds for 8 hours, there would be 960 data points for each of these data. Visualizing all these 1920 (960 each) data points in a single chart, the chart would get cramped with figures and look very messy for the users to understand them.

Similarly, visualizing different types of data together or separately, we may not be able to show all the detail about the data at one time, like if we are visualizing nominal or ordinal values together with other data, it would not be appropriate to show the text (ordinal and nominal values) together with figures. So there should be some mechanism for the user to obtain these information or details when s/he wants it.

Similarly, a data point contains the precise value which we may not be able to extract just by comparing them with the axes, for example, the user may not be able to get the precise value of a 25th data point of the noise data just by looking at the axis. This means that there should be some mechanism for the user to get these precise values.

When a user is reflecting on the experience through the support of visualization, getting more details whenever user wants can further support his/her reflection process. So, different levels of detail/details on demand can be taken as a visualization challenge which is also directly

related to high level requirements of finding *proper visualization and interaction techniques* and *supporting reflection*.

3.7.1.4 Data distinction

When we are visualizing different types of data, together or separately, each of the data must be distinctly identifiable for the user, otherwise the whole experience would be confusing and messy. Like in scenario 1, if the user is not able to distinguish between the noise data and temperature data, it would be confusing and hard for the user to extract any information from that visualization. Same in the case when s/he cannot distinguish between ordinal and nominal data. During the reflection session, if the user cannot distinguish between the data, the visualization would be of no help for him/her in the reflective process.

So this visualization challenge of keeping the data distinct from each other is directly related to high level requirements of finding *proper visualization and interaction techniques* and *supporting reflection*. If the user cannot distinguish between the data, s/he would have a bad experience working with that visualization. So this can also be related to the high level requirement of providing *good user-experience/usability*.

3.7.2 Analysis of Visualization and Interaction Challenges

In this sub-section, the analysis of visualization and interaction challenges identified in the previous sub-section would be done.

3.7.2.1 Correlation among data

To understand the correlation between data we can try to view them on a same chart, but it is very hard to do so as we have different types of data, like geo-location data which is generally visualized in a map and time-series continuous data which is usually visualized in the line chart. If we try to cramp them up in the same visualization, it is obvious that the data would not make much sense in that visualization. Time would be the only property that would be common in these types of data, so we can visualize them in different views but bounded or linked by the time property i.e. time-range selection in one would also affect the other. When the time-range is changed, both of these views would change based on it, and it would allow us to see any type of correlation between them.

User-submitted notes (ordinal and nominal data) can be visualized as some symbol (or icon) on a time-series line chart along with the continuous data. This is possible if we don't associate user-submitted notes with any of the y-axes. This has also been explained in my 'Specialization Autumn Project' [15]. These user-submitted notes can also be shown as some symbol or icon on the map along with the geo-location data. This way we can see if there is any correlation between these data.

So we can have

- Time-series line chart showing continuous data and user submitted ordinal and nominal data (as symbols or icons) together
- Map with ordinal and nominal data as symbols or icons
- different views that are linked together,
- 'Coordinated Multiple Views' [44] if the same entity is being visualized in different views

3.7.2.2 Filtering/Focusing

The time based filtering or focusing means we have to have a mechanism to select a time-range from an entire range or the overall context. This can be done by letting the user enter the range, or we show them the entire range and provide a mechanism to select a range. The latter is more user friendly as the user would not have to bother entering the time but rather just select from the range. This can be done through different techniques like

- providing the user to select start and end value of the range using dropdown selection options,
- using slider [45]
- zooming technique [46, 47] to zoom in to the interested part

When we want to focus on a certain range, it can be helpful to have the overall context visible to select from. This is a visualization technique popularly known as 'Focus+Context' Visualization [13, 47].

Filter interaction techniques[10] where the user can select the data that the user wants to view can make the filtering (or focusing) on a data or the combination of different data possible.

3.7.2.3 Different Levels of detail/Details on demand

The data can be viewed in different levels of detail by using different techniques like

- 'Focus+Context' Visualization technique to show the details in the focus view and overview in the context view
- 'Zooming' on the area to view the part in more detail
- 'Drill down' on the part of the area to view more in detail [10]

The 'tooltip' or 'highlight' interaction technique can also be used to view the details on demand [10].

3.7.2.4 Data distinction

To differentiate a data from the other we can follow different techniques like

- color consistency – keeping the same color for the data anywhere it appears [48]
- the data is represent the same way in every place it appears i.e. same symbol, figure, etc.
- emphasize the data in every view when selected or under focus, also known as 'Connect' interaction technique [10]

4 Related Works

This chapter presents the related works that has been done which are in some way relevant to this thesis.

4.1 Sensor data and Visualization

With the advancement of technology, devices that are small and efficient in collecting variety of data through variety of sensors are abundantly available these days. Popularity of very small and inexpensive but fully functional computers like Raspberry Pi [49, 50], inexpensive and open-source hardware components like Arduino [51], and ubiquitous adoption of smartphones and wearable devices equipped with variety of sensors has made the data collection through sensors a non-complicated task. Likewise, the increase in popularity of Internet of Things (IOT) concept, more devices are getting connected to the internet and are collecting large amount of data.

Collecting data is one part and making sense out of those data is the other. Visualization has been proven to make it easier to understand data if they are properly used. But it may not be an easy task to identify a proper visualization for the data you want to understand. Some of the works has been done towards making guidelines for identifying visualization techniques for the sensor data. By discussing on the taxonomy of sensors and all the possible types of sensor, papers [52, 53] has attempted to make a guideline for matching visualization with sensor data.

Paper [54] has presented an extensible visualization and interaction platform to visualize and interact with variety of sensor data. The platform allows the user to experiment with different visualizations and validate the ones suitable to the context and to the user's needs.

4.2 Experience Sampling Method and Reflective Learning

In Experience Sampling Method (ESM), a person keeps notes of his/her feelings, thoughts, activities or experiences s/he is going through right at the time of note keeping [55, 56]. Usually, this is done in a certain fixed interval of time pre-scheduled during the day. Many variants of ESM have also been introduced that are based on the concept of ESM, like Image-Based Experience Sampling [57], Context-Aware Experience Sampling (CAES) [58], Contextual Activity Sampling System (CASS) [59], Ecological Momentary Assessment

(EMA) [60], Event Sampling Methodology [61], etc. ESM has been used mostly by the researchers to collect information from the volunteers and candidates, but since it can contain highly personal and subjective contents, it has also been adopted by many to be used for the purpose of reflective learning.

Papers [62, 63] present how the use of mobile devices for collecting experience related data helped the students to reflect on their activities and help them to structure their lives. Paper [57] explains about image-based experience sampling methodology in which a camera is used to capture images based on which the user can reflect and comment on the experiences depicted by those images. Paper [64] explains how the designers and students used the CASS (Contextual Activity Sampling Method) based mobile devices to record their experiences during the designing process by reflecting on the experience and learning on the process. A researcher has conducted a simple paper based ESM to capture the creative process that he went through in his research and found that ESM was very effective in the initialization of his reflection process [65]. Paper [66] discusses on the research where the students who used contextual activity sampling method had a better reflection and learning than the students who did not use the method.

4.3 Reflective Learning in Personal Informatics (Quantified Self)

A class of systems or tools known as 'Personal Informatics' that helps people to collect and track their personal information for the purpose of self-monitoring and self-reflection are getting popular these days [67]. And the community of people and developers adopting these systems and collaborating with each other are referring to the movement as the 'Quantified Self' [68]. In a broader sense, the terms 'Personal Informatics' and 'Quantified Self', and sometimes 'Personal Analytics'[69], are often found to be used interchangeably [67].

Paper [70] has proposed a five stage-based model for building the personal informatics systems that supports and ensures reflective learning in the users. Paper [71] discusses on the use of 'Personal Informatics' for the purposes of reflective learning and has identified two distinct phases of reflection and six types of questions that people go through during reflective learning process. The paper advocates on developing tools based on these findings so as to support proper reflective learning experience on users.

To support reflective learning as described by Boud et al., paper [72] has proposed a framework that can be applied in developing 'Quantified Self' based tools and applications. The framework is based on three dimensions, namely (i) tracking cues, (ii) triggering reflection and (iii) recalling and revisiting experiences. Based on this framework, paper [73] explains about the development of an application 'Live Interest Meter' that utilizes the user feedback to support the reflective learning in the lecturer.

Paper [74] explains the use of 'Personal Informatics' based application to help the people reflect on the contextual data collected by the application to help them evaluate their personal values in everyday contexts.

There are numerous software tools based on 'Personal Informatics' or 'Quantified Self' developed for the purpose of reflective learning, like to assist knowledge workers [75], to help children with ADHD [76], for personal journal based reflective learning [77], to help Diabetes patients on their diabetes management goals [78], to help cancer patients realize the benefits of cancer treatment [79], etc.

4.4 Visualization to support Reflective Learning

There has been many works done in using visualization to directly or indirectly promote reflective learning. Papers [35, 80, 81] present different visualization tools and techniques intended to help the students in self-reflection and self-monitoring to improve their learning behaviors or activities.

To provide users a way to self-reflect on their behaviors and personality based on the bookmarks they keep in their web-browser, paper [82] describes a visualization approach for visualizing those bookmarks. Paper [83] presents a visualization tool, ReflectionSpace, targeted to support reflection-on-action among designers to explore their own design processes, and through the user evaluation it was found to be helping the designers in their reflective activities.

Paper [84] describes the designing of a modified star-plot visualization called pieTime for visualizing user's email and phone activities, which is intended to reveal temporal rhythms in user's behavior and to encourage self-reflection in the user. Paper [85] presents the use of visualization to help older adults in self-reflecting for the purpose of helping them self-

monitor their blood pressure. Paper [86] presents a visualization tool, Feeler, that is intended to help users in self-reflecting and self-monitoring some aspects of their lifestyle or well-being.

Some works has been done towards creating guidelines for developing visualizations for supporting self-reflection. Intended for designing 'Personal Informatics' systems, but applicable to similar fields or cases, paper [87] proposes four data visualization heuristics for designing and evaluating system that facilitates self-reflection in the users. These heuristics can be taken as the guidelines for developing visualization based systems that can visualize self-tracked data which would promote self-reflection in the user.

4.5 Role of Interaction in Visualization

According to Card et al. (1999) [13] information visualization is "*the use of computer-generated, interactive, visual representations of data to amplify cognition*". So, information visualization (InfoVis) constitutes a close relationship between human cognition, computer generated visual artifacts, and user interaction. An InfoVis system have two components in its core: representation (visualization) and interaction, and without interaction the InfoVis system would be no different than a static image [10]. And so, visualization alone would not be able to provide as much insights as it would have been possible along with interaction [88] because interaction permits further exploration [10]. Pike et al. argues that interacting with visualization is in fact the analytic discourse and it should not be taken as separate entities [89].

Several works has been done towards classifying or building taxonomies of interaction techniques. Paper [90] has tried to put together a taxonomy of interaction techniques, more precisely task-by-datatype taxonomy, based on the different types of data to be visualized. Paper [91] presents a basic classification taxonomy based on BVI (Basic Visualization Interactions) which are the interaction/semantic primitives decomposed from interactive systems. Paper [10] presents a seven category taxonomy of interaction techniques through a comprehensive survey of interaction techniques in InfoVis.

5 Design & Implementation

In this chapter, the system design will be explained in detail. The functionality and the design of both the VRL application and VRL Data Collection application will be described using diagrams and screenshots.

5.1 General Description

This section describes how the two applications work and their respective goals. The VRL application is a web-based application used for visualizing the user-related data in order to help the user in reflecting about his/her experience represented by those data.

The VRL Data Collection application is a mobile application to assist user in collecting information about themselves. It allows the user to inputs nominal texts and/or ordinal values while collecting some sensor data automatically. For the collection of GPS data, the application will also need the internet connection.

5.2 VRL application

VRL application is the main application that would be used for visualizing and interacting with the user-related data. This section presents the design choices made for the VRL application.

5.2.1 Visualization and Interaction Choices

During the analysis of the visualization and interaction challenges, several visualization and interaction techniques were identified. Looking back at the analysis of data and the identified suitable visualization and interaction techniques, here I discuss on them and make the choices among them to be implemented in the application.

'Focus+Context' visualization technique allows focusing or viewing in detail the part of the data that the user is interested in while still being able to have the overview of the context [13]. The basic idea is to show the object of primary interest in greater detail while simultaneously showing the global context without any occlusion. Graphical Fisheye View [92], Rubbersheet View [93], Table Lens [94], Document Lens [95], Cone Trees[96], etc. are some of visualization techniques or strategies based on the Focus+Context visualization.

In our problem, we have different types of data representing the user's experience over a certain period of time. If we use 'Focus+Context' visualization, we can show the entire data (entire experience) in the 'Context' part from where the user can select the parts s/he is interested in to be focused (which can be shown in the 'Focus' part). So we would have at least one 'Focus' and one 'Context' part. This makes much sense as we would always be able to look into the entire experience and explore around the interested part in more detail. This will partly be solving our 'Filtering/Focusing' challenge as well as 'Different levels of details/Details on demand' challenge.

As discussed before, we have the challenge of visualizing combination of data, and we can visualize continuous data and user-submitted data (nominal and ordinal data) together in a same time-series line chart. But we still have to associate this combination with geo-location data. With 'Focus+Context' visualization technique, we need a 'Context' where we can see all these data together, a 'Focus' where we present the combination of continuous and user-submitted data, and a 'Focus' where we show geo-location data. Since all the different types of data have only time as the common attribute, we can call the 'Context' where we present all these data as 'Timeline'. In 'Timeline' we can present these data based on the time they were created or collected by representing them in a straight line to denote their presence during the actual experience. This way the start and end of the line would mean when the data was created (or started collecting) and when they were stopped (or stopped collecting). This way we can see an overview of when each data was present and also make it easier to select a time-range to focus on.

The 'Focus' where we are visualizing the combination of continuous data and user-submitted data (nominal and ordinal data) would be a multi y-axes line chart where the continuous data would be represented by lines and user-submitted data with some symbols. Line charts are the most common and popular ways to visualize any time-series continuous data and it would make much more sense to visualize them like that. User-submitted data would be textual notes

and it would not be a clean visualization to show line chart with texts in it. So, user-submitted data can be visualized as a symbol in the line chart, but associated only with x-axis which represents time. This way we can see both the continuous and user-submitted data on the same chart and through this it may be easier to see the correlation between them. We can call this chart as 'Focus (Detail View)' chart.

We can show the geo-location data as the path taken by the user in a 'Map' chart. This would make it easier for the user to see where s/he been and which path s/he took during the experience. This chart will also be a 'Focus' as we can show path based on the data within the time-range selected in the 'Context' charts/panels. This way the user can narrow down the time-range and figure out where s/he were in that particular time-frame.

In 'Focus (Detail View)' chart we can view the data closer and in detail. And since it is a 'Focus', it would be very easy if we have the entire view as well. So we can have another chart, visually similar but for the overview or as a 'Context'. We can call this chart 'Context (Overview)' chart.

In the 'Focus (Detail View)' and 'Context (Overview)' charts, user-submitted data (nominal and ordinal data) would be represented as some symbols. But we need a way to see the actual values they hold. This can be done by 'Highlight' or 'Tooltip' interaction technique where, when the user highlights or hovers around the data (symbol), the values would be displayed in a tooltip hover box [97]. We can also use the 'Highlight/Tooltip' interaction technique to see the precise value of each of the data-nodes of lines in the line chart that represent the continuous data.

Since there can be a lot of user-submitted data, both nominal and ordinal data, and some user may be interested to see their values together at once and not just while they highlight them, we can display the list of user-submitted nominal and ordinal value in a separate panel, namely 'User Notes'. This panel can also be considered as 'Focus' because we can display only the values that are on the selected time-range in the 'Context' charts/panels.

We would have geo-location data represented as a line in 'Timeline' chart based on when it was started to collect and when it was stopped, and as a path line in the 'Map' chart. Similarly with user-submitted data, they would be represented as a symbol in the 'Focus (Detail View)' and 'Context (Overview)' charts, while as textual notes in the 'User Notes' panel. The same can be said with the continuous data, which would be represented as a straight line in the

'Timeline' chart, while on Focus (Detail View) & Context (Overview) charts as a line with data-points or nodes representing value on that particular time, and it may not be a straight line. With all these different forms a data may take in each of the charts/panels, it can be called 'Multiple representation' of the same data.

Since, for a same data we would have 'Multiple representation', we need to make sure that each data are distinct and easily recognizable in there different forms across different charts/panels. We can use the 'Color consistency' approach where a data would be visualized with the same color despite the different forms they take.

Allowing 'Color encoding'[10] interaction technique for the user to change the color of any data during runtime, we can let the user select the color of that data based on their preference. Similarly when we interact with the data, we can also use the 'Connect' or 'Emphasize' approach to present it with more emphasis, like by increasing size a little, changing color to stronger color, etc., in their different forms to make them easily recognizable.

We can also let the users to show/hide any data, or 'Filter' among the data, so that the user can display only the data (or a combination of data) s/he is interested in at the moment. This would make the exploration of the data much easier for the user. This ensures that the user can focus on the data of interest and won't be overwhelmed by a lot of contents.

For the user to select a time-range in the 'Context' charts, we can use time-range 'Slider' in which one end of the slider represents the start and the other end represents the end of the time-range. This way the user can slide each end of the slider to adjust the time-range the user is interested in. Similarly we can also allow the 'Zooming' technique in the 'Focus' so that the use can focus on the certain time-period by zooming in the area. With zooming we will also need panning[10] to allow the user to pan or move to see the adjacent area. In case of 'Context' where the slider is used, we can allow dragging of the whole slider (but not just its ends) to see adjacent areas just like panning but through 'Context' charts.

Since ordinal data represent values that are in some kind of order that the user can easily understand or relate to. This property of ordinal data can be utilized in the visualization. I propose to display the ordinal values in different heights based on the order of the value and call it 'Ordinal placement of the ordinal values'. Here, if we take the ascending approach, the value at the first place in the order would be displayed at the lowest height and the value at the second place in the order would be displayed at a certain height higher than that of the first

value, and so on for the rest of the values. This way, the height placement of a certain value represent the order of that value in the ordinal rank. This can also be done in the descending approach, based on the type of the ordinal values. This approach will allow the user to easily identify the trend/pattern of the ordinal values and may help in correlating it with other data. . This has also been explained in my 'Specialization Autumn Project' [15].

To summarize, these are the visualization and user interaction techniques I want to apply in the application.

Table 12 Chosen Visualization techniques

Visualization technique	Reason
i. Focus+Context	- To let the user focus on the interested part of the data in 'Focus' while still having the overview of the entire context through 'Context' - To filter the data to see only the selected or interested part in the 'Focus' - To support 'different levels of details and/or details on demand'
ii. Multiple representation	- To make it easier for the user to extract different information from the same data
iii. Color consistency	- To make the user identify a data easily across different charts/panel
iv. Emphasize/Connect	- To make the user identify or recognize a data easily across different charts/panel
v. Ordinal Placement of Ordinal Values	- To make it easier for the user to identify each of the ordinal values based on their placement - To make it easier for the user to figure out the trend/pattern of the values and understanding any correlation with other data.

Table 13 Chosen User-interaction techniques

User interaction technique	Reason
i. Highlight/Tooltip	- To see the value of ordinal and nominal values in the 'Focus (Detailed View)' chart - To see the precise value of each of the data nodes of lines (continuous data) in the 'Focus (Detailed View)' chart
ii. Color Encoding	- To let the user to change the color of data according to his/her preferences
iii. Filter	- To let the user to show/hide the data based on their interest
iv. Zooming	- To change the scale of the view to see the view closer and in more detail - To filter the area and only focus on the area of interest
v. Slider	- To change the scale of the view to see the view closer and in more detail - To filter the area and only focus on the area of interest
vi. Panning	- To see the adjacent section or area of the view without changing the scale
vii. Dragging	- To see the adjacent section or area of the view without changing the scale

5.2.2 VRL Application Design mockup

In this section, the mockup design for the VRL application is shown which is based on the identified charts/panels in the previous section.
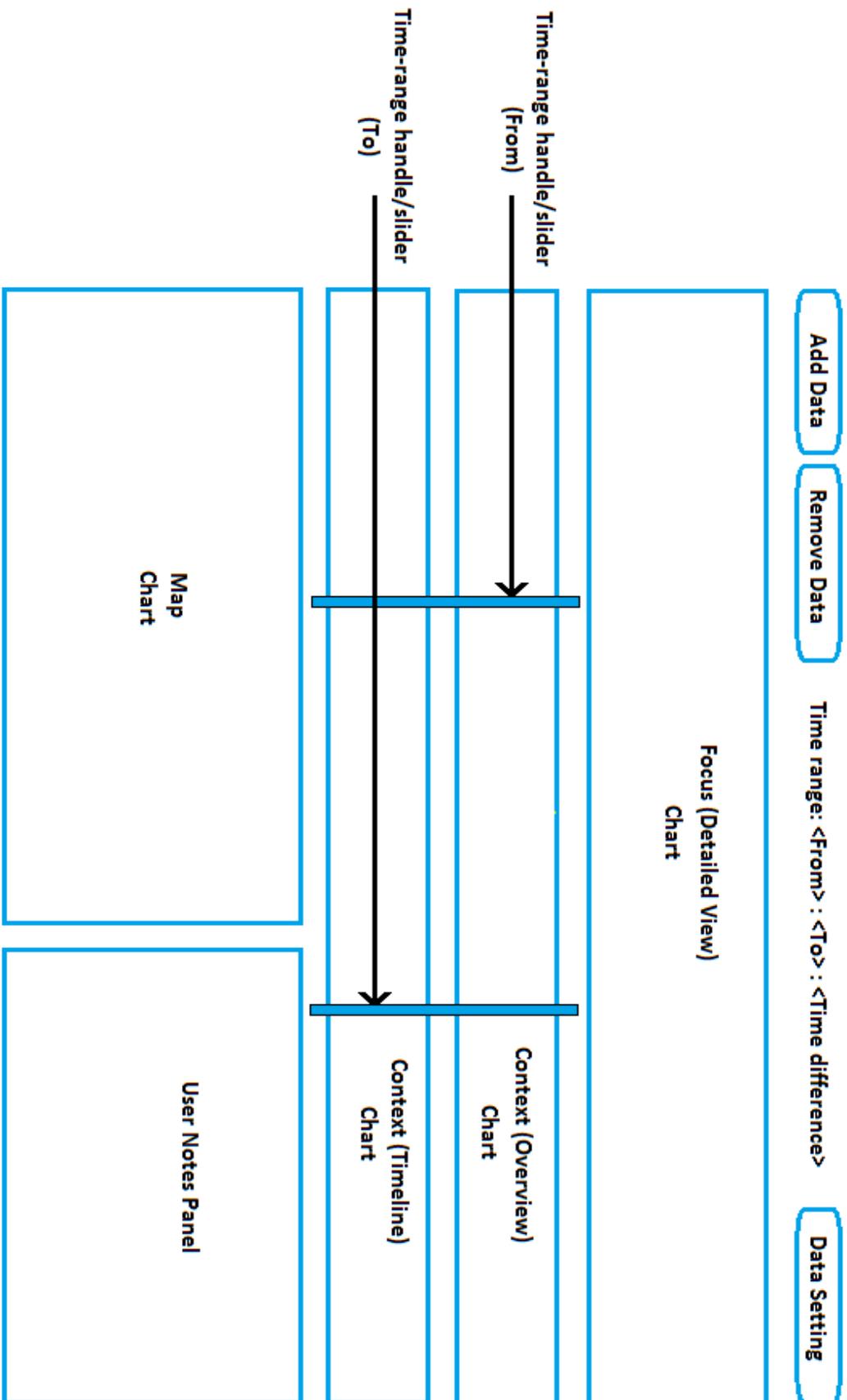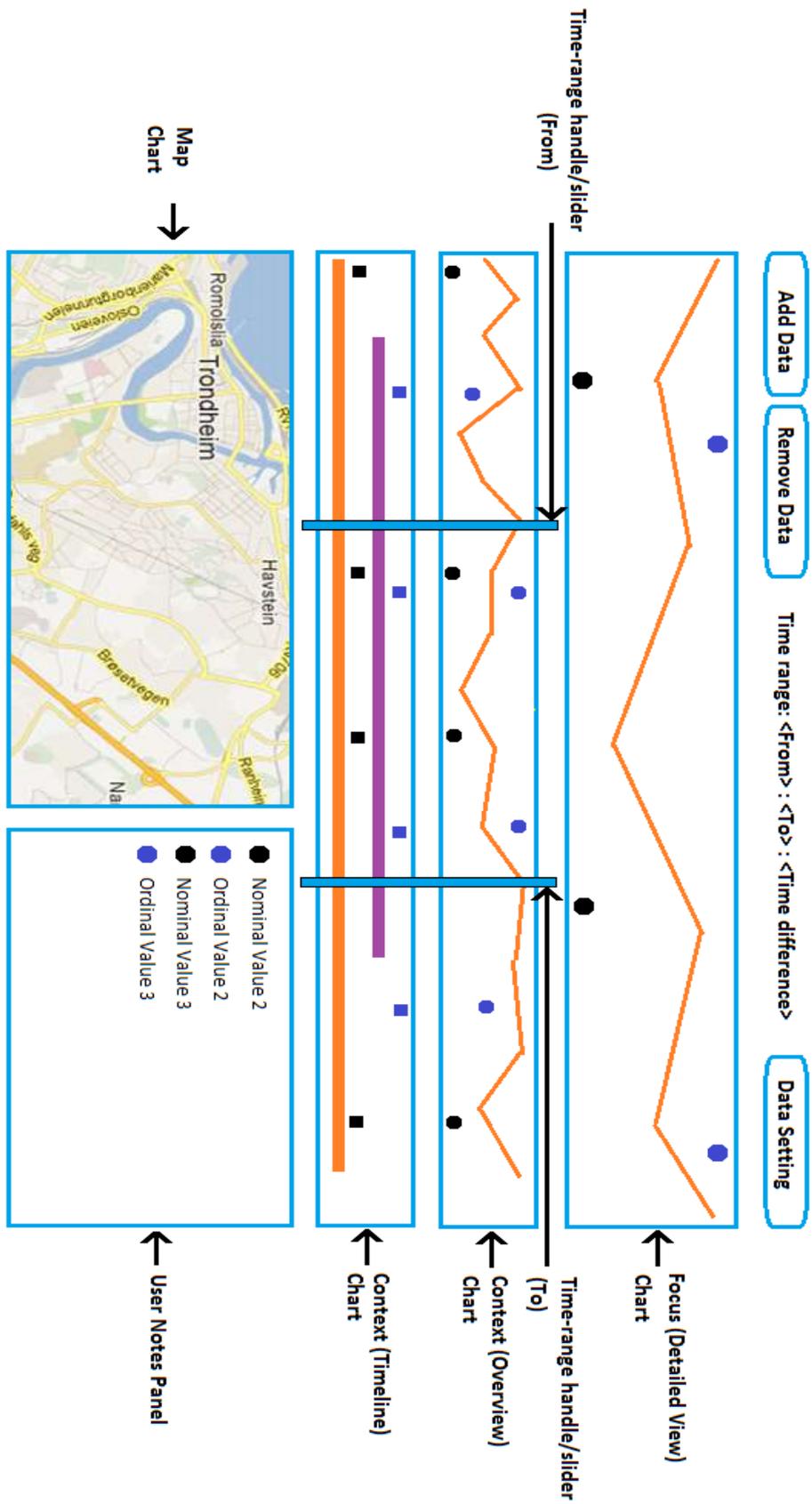
Figure 7 VRL application design mockup (outline)

Figure 8 VRL application design mockup

5.2.3 Requirement Analysis

The chapter describes different functional and non-functional requirements for the application being developed.

5.2.3.1 Functional Requirements

The functional requirement of any software refers to the different functions the software must be able to perform.

Table below describes the functional requirements of the application.

Table 14 VRL Application: Function requirements

ID	Name	Description
1	Create a new 'Reflection Session'	User can create a new 'Reflection Session' in the application where the user can add user related data and reflect upon them
2	Add data	User can add a type of data into a 'Reflection Session' already created
3	Reset reflection	User can reset the "Reflection Session" by deleting all the data that had been added into the 'Reflection Session'
4	Customize color of each data	User can change color of each of the data previously added to the "Reflection Session" according to personal preference.
5	Filter data	User can filter or show/hide each of the data from the "Reflection Session" at the runtime
6	Zoom in/out	User can zoom in or zoom out the visualized data to focus on the interested part (line charts and geo charts/maps)
7	Pan the view	User can pan on the view to see the areas the user wants to see (applicable when zoomed in)
8	Slide a time-range handle	User can slide time-range handles to filter the areas of interest based on time (from Context)
9	Drag time-range handles	User can drag both the time-range handles to view the areas of interest (from Context)
10	Highlight/select each data	User can select and highlight each data in the visualization

5.2.3.2 Non-functional Requirements

Non-functional requirements describe how the software performs or works. These requirements are not the specific operations but rather the behaviors through which different operations of the application can be judged.

5.2.3.2.1 Usability

The application is not designed for some specific group of people but the user can be anyone. So the application must be easy enough to be used by everyone. So the user interface must be simple and intuitive.

5.2.3.2.2 Performance

Good performance is the must in any software, so the application being developed must also have a good performance. Each of the user actions must be performed with minimum time lag of about 0.5 seconds or less.

5.2.3.2.3 Scalability

Typically a user would not have a lot of data but in case the user have, the application must be able to handle them.

5.2.4 Technological Choices

This section describes the technological choices made for the VRL application.

5.2.4.1 Web Platform

The main objective of the VRL application is to visualize user-related data and let the user interact with them. There are mainly two approaches to developing such type of application, either Desktop-based or Web-based, and in both of these approaches there are numerous visualization libraries and tools available.

Desktop based application are platform dependent. These types of application are closer to the platform and thus can take advantages of the hardware features. Because of this the performance of desktop application are also better. Desktop application are usually build using the programming languages like C, C++, Java, etc.

Web-based application are platform independent and run in a web-browser. So web-based application usually requires a network or connectivity to operate. Web-based application requires HTML, CSS and JavaScript programming for the client-side and can use Java, Python, JavaScript (Node.js), etc. for the server side.

For the development of the VRL application I have chosen the web-based approach. Being cross-platform compatible ensures that the application can be readily used in all other platforms without much hassle. The user also do not have to worry about installation of the application in their system. These days, even normal computer/laptop system are packed with good processors and multiple gigabytes of memories and web-browser speeds are getting better. So, the VRL application won't have much of the performance issue as it won't be dealing with large amounts of data but just few megabytes of data at most.

The application would be based on Client-Server architecture, where client-side would deal with visualization and interaction and the serve-side for data handling. One of the obvious reasons to follow this architecture is that, with web-based applications, client-side have limited control over the client's operating system and so they won't have access to file handling. For this reason we need a server to handle the files and data, and we can also run multiple client-side of VRL application at the same time. For the client-side, standard programming languages HTML, CSS and JavaScript will be used. For server-side scripting, there are many options available like ASP.NET, Java, PHP, JavaScript (Node.js), Python, Ruby, etc. For the VRL application I am choosing JavaScript (Node.js), one of the main reason is that I won't have to switch to a new programming language while building the entire application. And since the main focus of the application is on the visualization and interaction, which are client-side tasks, there are very few server-side tasks like uploading and saving files into the system, so using JavaScript (Node.js) would be a quick and efficient solution.

5.2.4.2 Visualization Library/Framework

There are numerous JavaScript based visualization libraries or frameworks available. This section presents some of the popular JavaScript visualization libraries and the choice made for the application.

5.2.4.2.1 D3.js

D3 is an acronym of Data-Driven Document [98] and D3.js is one of the most popular JavaScript visualization library. It is an open source JavaScript Library that implements W3C

web standards like SVG, HTML, and CSS for producing dynamic and interactive visualizations. Because of this, D3.js is considered reliable in rendering correctly in almost all web-browsers. D3.js is flexible and powerful in the sense that it lets the developers to design their own visualizations from scratch. It has a good documentations and a large community of developers and examples. It has a difficult learning curve for the new developers or designers.

5.2.4.2.2 Processing.js

Processing.js is based on 'Processing'[99] which is a programming language for developing interactive visualizations. Processing is a general purpose language with simple syntaxes that is easy to use even without much prior programming knowledge. Using Processing.js, most of the code written in 'Processing' language can be visualized in the webpage without a lot of work. Processing is closed proprietary system.

5.2.4.2.3 Google Charts API

Google Charts API provides a large gallery of very simple to complex ready to use charts. Even people with little technical knowledge can easily use google charts as these charts are easy to implement. Google charts requires to connect to the Google Charts API to function, so they need to be connected to the internet.

5.2.4.2.4 Visualization library of choice

D3.js library was chosen for the VRL application. The application has specific visualization requirements like building 'Focus (Detail View)' chart, 'Context (Overview)' chart, etc. so D3.js will be the right tool as it has the flexibility to do so. The other reason to choose D3.js over other libraries is that it has a large volume of examples and a large community of developers that would be helpful during the development. And another reason is that I had a previous knowledge on using D3.js, so I would not have to spend much time on using it.

5.2.5 Data format (File Format)

There are numerous data exchange formats like XML, RDF, JSON, EBOL, etc. For the VRL application JSON format (JavaScript Object Notation) was chosen. One of the reason is that it is an open standard format, and is simple and human readable. It is language independent data format and almost all programming languages have readily available parsing feature for this data format. Being simple, lighter and native to JavaScript on which the VRL application would be developed, this format was chosen for the data format.

The structure of the data format for the VRL application is as follow:

```
{
      "name"     : "<data_name>",
      "Source"   : "<data_source>",
      "type"     : "<data_type>",
      "valueInfo" : {
           "max" : "<max_value>",
           "min" : "<min_value>",
           "unit" : "<value_unit>",
           .
           .
           .
      },
      "values" : [
           {
                "timestamp" : "<timestamp1>",
                "value" : "<value1>"
           }, {
                "timestamp" : "<timestamp2>",
                "value" : "<value2>"
           }, {
                "timestamp" : "<timestamp3>",
                "value" : "<value3>"
           },
           .
           .
           .
      ]
}
```

5.2.6 Application Architecture

5.2.6.1 Client-Server Architecture

As mentioned earlier in Design chapter, the VRL application is based on the Client-Server architecture. VRL application runs in a dedicated Node.js server and many clients can access VRL application at the same time through the web-browser. To visualize a data, user will have to load (upload) the data file into the server; the server-side will save the file into the system and then send the data to the client-side logic which will visualize it for the user. Most of the works are done in the client side of the application; it is where the data is visualized and the user's interactions are processed and acknowledged.

Node.js is an open-source server-side JavaScript environment based on Google's 'V8' engine [100].
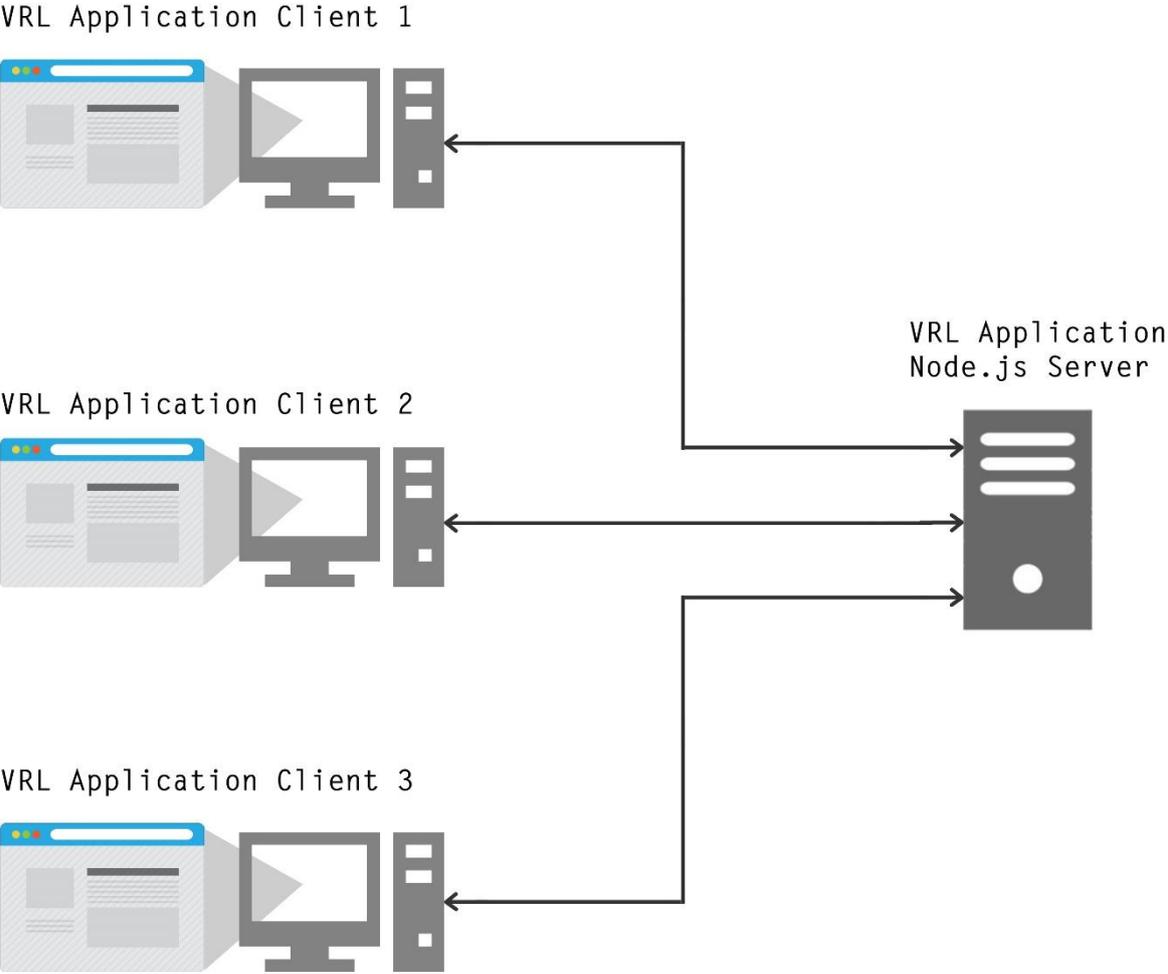
Figure 9 VRL Application Client-Server Architecture

5.2.6.2 Model-View-Controller Architecture

The client side of the application is based on Model-View-Controller (MVC) architecture pattern. MVC pattern is used to separate an application into three different types of components: Model, View and Controller. Model represents data or an object carrying data, View represents the visualization of the data that Model contains, and Controller acts as the link between Model & View. When the user tries to interact with the View, the user actually would be using the Controller to manipulate the Model, the Model would be notifying the

changes to the Controller, then the Controller will update the View, and these changes on View are what the user will see.

Figure 10 MVC Architecture Pattern

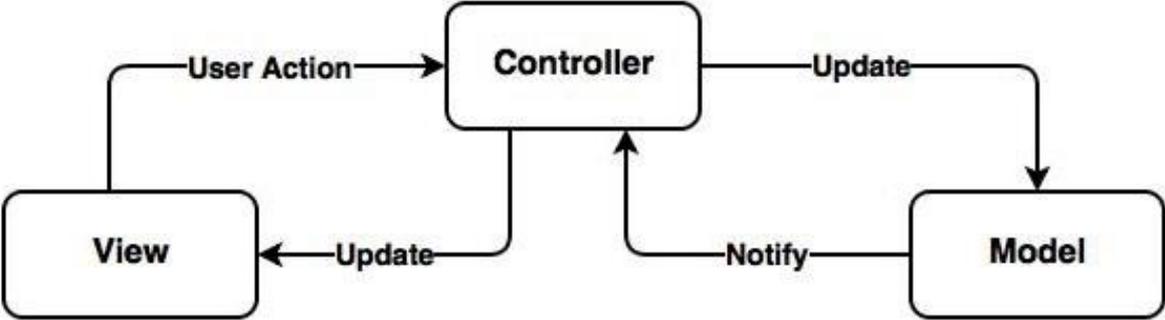In the VRL application, Models are the objects containing the data and the look & feel information about those data. Similarly, the Views are each of the charts/panels in the application. Controllers are the objects that are responsible for handling the user-interactions and updating the Models (thus eventually Views).

In the application, users can see the Visualizations (Views) with which they can interact by using different interaction techniques (Controllers). The user interactions would cause the changes in the look & feel information about the data (Model), which will cause the modification on the Visualizations (Views).

5.2.6.3 Observer pattern

Even though MVC pattern in itself is related to Observer pattern [101], the client side of the VRL application is also utilizing the Observer design pattern independently from the MVC logic as well. In the observer pattern, there is a one-to-many relationships between the objects where the one object, called subject, will keep the list of its dependents and notifies them when there is a state change in it. The dependent objects, called observers, will be updated automatically when the state change occurs in the subject.

When the data is loaded in the VRL application, the data would get visualized in multiple charts/panels.

Table 15 Data type and Charts/Panel where they are visualized

Data Type	Chart/Panel
Continuous data	i. Focus (Detailed View) chart ii. Context (Overview) chart iii. Timeline chart
Geo-location data	i. Map chart ii. Timeline chart
Ordinal Data	i. Focus (Detailed View) chart ii. Context (Overview) chart iii. Timeline chart iv. Notes Panel
Nominal Data	i. Focus (Detailed View) chart ii. Context (Overview) chart iii. Timeline chart iv. Notes Panel

Since the data is visualized in the multiple charts/panels, these charts/panels are linked together using the Observer pattern such that when there is some changes or interaction with the particular data in one chart/panel, the effects of the changes or interaction would also get reflected in other charts/panel where the data is present.

For example, if a nominal data item in the Focus (Detailed View) chart is highlighted, the same data item would get emphasized in Context (Overview) chart, Timeline chart and Notes Panel. Similarly, if the time-range slider in Timeline chart is moved to change the selected time-range, the selected time-range for all other chart/panels would change and visualization in each of the charts/panel would change based on that time-range.

5.2.7 Use cases

In this sub-section, the use-cases for the VRL application are presented in the textual form.

Use Case 1: Create a new 'Reflection Session'

Purpose	So that the user can start loading and visualizing their data
Precondition	Application server must be running
Step 1	Load the application's start page
Comments	When the start page is loaded, there won't be any data already loaded so it would be a fresh 'Reflection Session' for the user to load and visualize data

Use Case 2: Add data

Purpose	To allow the user to add the different types of data collected during their actual experience to be visualize during the 'Reflection Session'
Precondition	A 'Reflection Session' is active
Step 1	Click 'Add data' button
Step 2	Select/Choose the data file (or enter filepath)
Step 3	Click 'submit'

Use Case 3: Remove data / Reset

Purpose	To remove the previously loaded data from the 'Reflection Session'
Precondition	Some data are already added to the 'Reflection Session'
Step 1	Click 'Reset' button
Step 2	Click 'Yes' in the confirmation dialog
Comments	All the data previously added would be removed and the 'Reflection Session' would be empty as a new 'Reflection Session'

Use Case 4: Customize color of each data

Purpose	To change the color of the data in each of the charts/panels according to the user's preference
Precondition	At least one data is already loaded
Step 1	Click 'Data setting' button
Step 2	Click color palette for the data of choice
Step 3	Select the color from the palette
Comments	The visualization of the data, whose color is being changed, would change during the time of selection for the user to see how the visualization would look with the current selection

Use Case 5: Filter data

Purpose	To show or hide the data of choice
Precondition	At least one data is already loaded
Step 1	Click 'Data setting' button
Step 2	Check or uncheck the 'Show' checkbox of the data that the user wants to show/hide
Comments	By default, the data would have the 'Show' checkbox checked

Use Case 6: Zoom in/out

Purpose	To change the scale of the visualization in order to focus on a certain part or for scale back to normal
Precondition	At least a data (continuous, nominal or ordinal) is already loaded
Step 1	Put the mouse cursor over the visualization
Step 2	Roll the mouse wheel (or track pad) forward or backward
Comments	Currently works only in Focus (Detailed View) chart Zooming in or out will also change the time-range selection in all other charts/panels

Use Case 7: Pan the view

Purpose	To change the visible view of the visualization without changing the scale
Precondition	Visualization is previously zoomed in
Step 1	Left mouse button pressed down on the visualization
Step 2	Drag the mouse left or right without lifting the mouse button
Comments	Currently works only in Focus (Detailed View) chart Panning the view in Focus (Detailed View) will also change the time-range in all other charts/panels

Use Case 8: Slide time-range handles

Purpose	To change the time-range selection (From or To of the time-range selection)
Precondition	At least one data is already loaded
Step 1	Left mouse button pressed down on one of the time-range handles (From or To)
Step 2	Drag the mouse left or right without lifting the mouse button
Comments	Works in Context (Overview) and Timeline charts Sliding time-range handles will also change the time-range for all other charts/panels

Use Case 9: Drag time-range handles

Purpose	To change the time-range selection for the focus charts – Focus (Detailed view), Map Chart and User Notes panel
Precondition	At least a data is already loaded
Step 1	Left mouse button pressed down in the area between the two time-range handles
Step 2	Drag the mouse left or right without lifting the mouse button
Comments	Works in Context (Overview) and Timeline charts Dragging time-range handles will also change the time-range for all other charts/panels

Use Case 10: Highlight/select each data

Purpose	To display additional information or emphasis the visualization of a data
Precondition	At least a data (continuous, ordinal or nominal) is already loaded
Step 1	Hover over/or click on the visualization of the data
Comments	Currently works only in the Focus (Detailed View) chart Highlighting data would display the additional information about the data in the tooltip that would popup in the visualization.

5.2.8 Application Screenshots

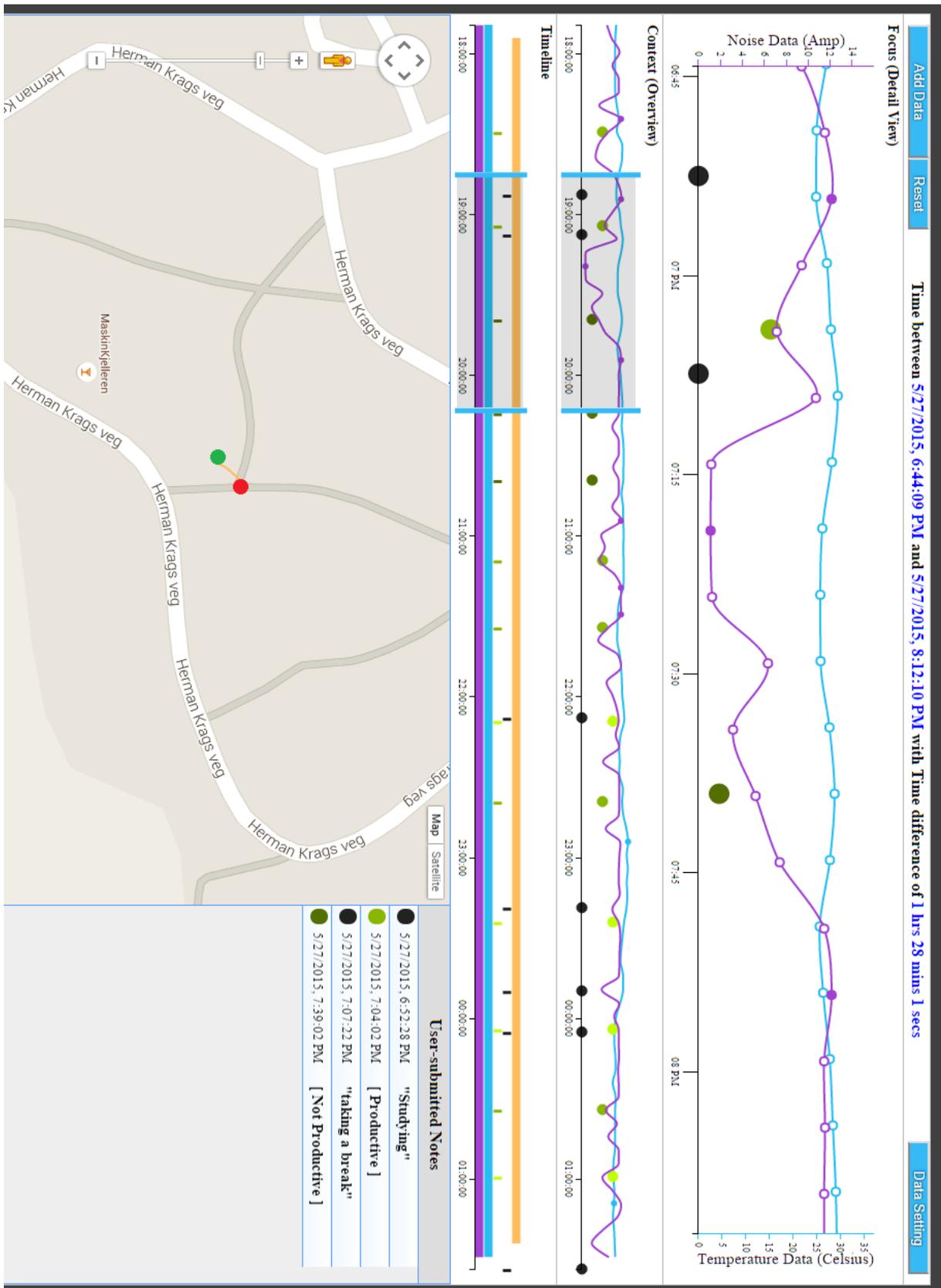In this subsection, the screenshots from the actual application are shown.

Figure 11 VRL application: Main View with partial time-range selection
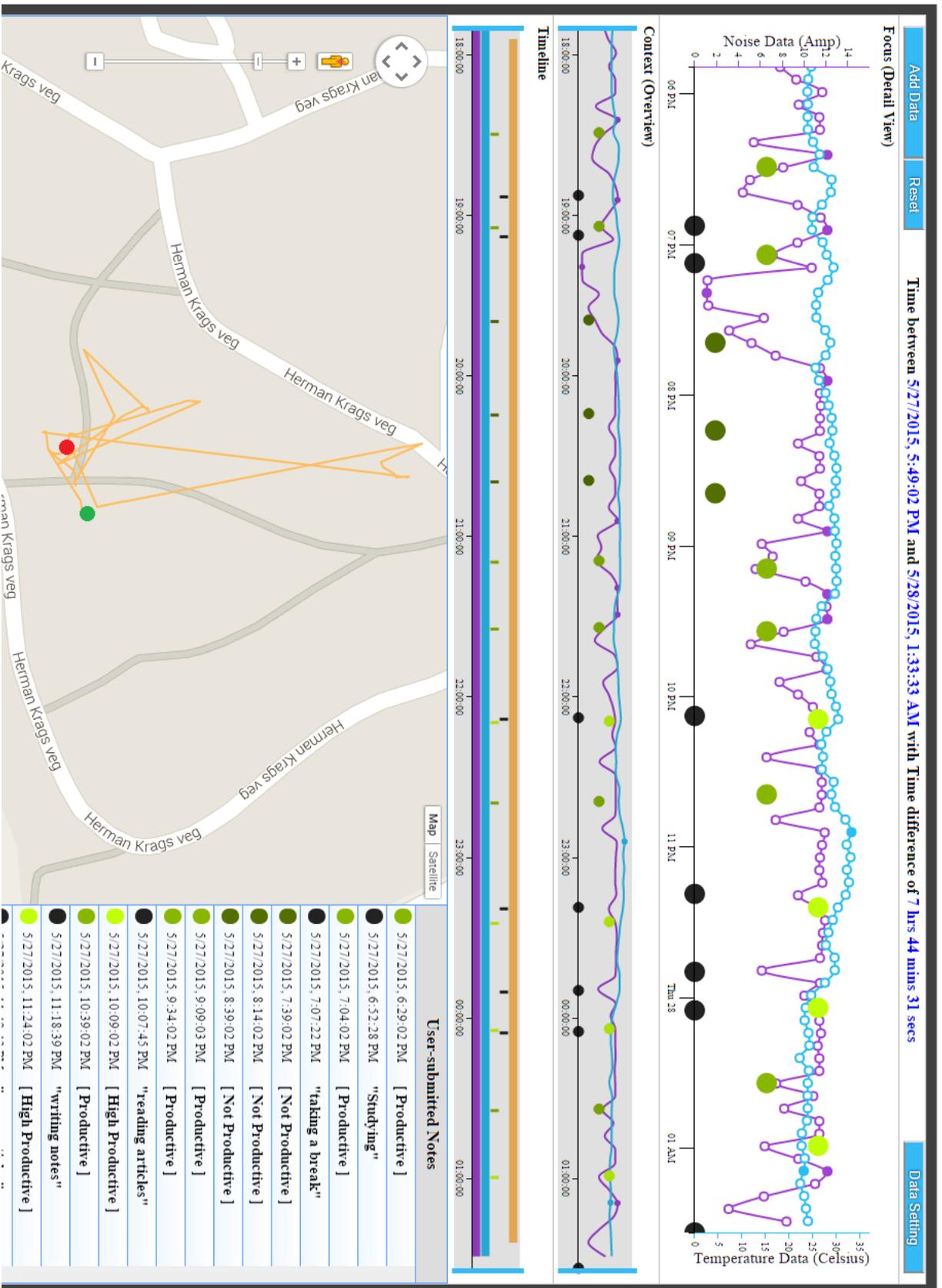
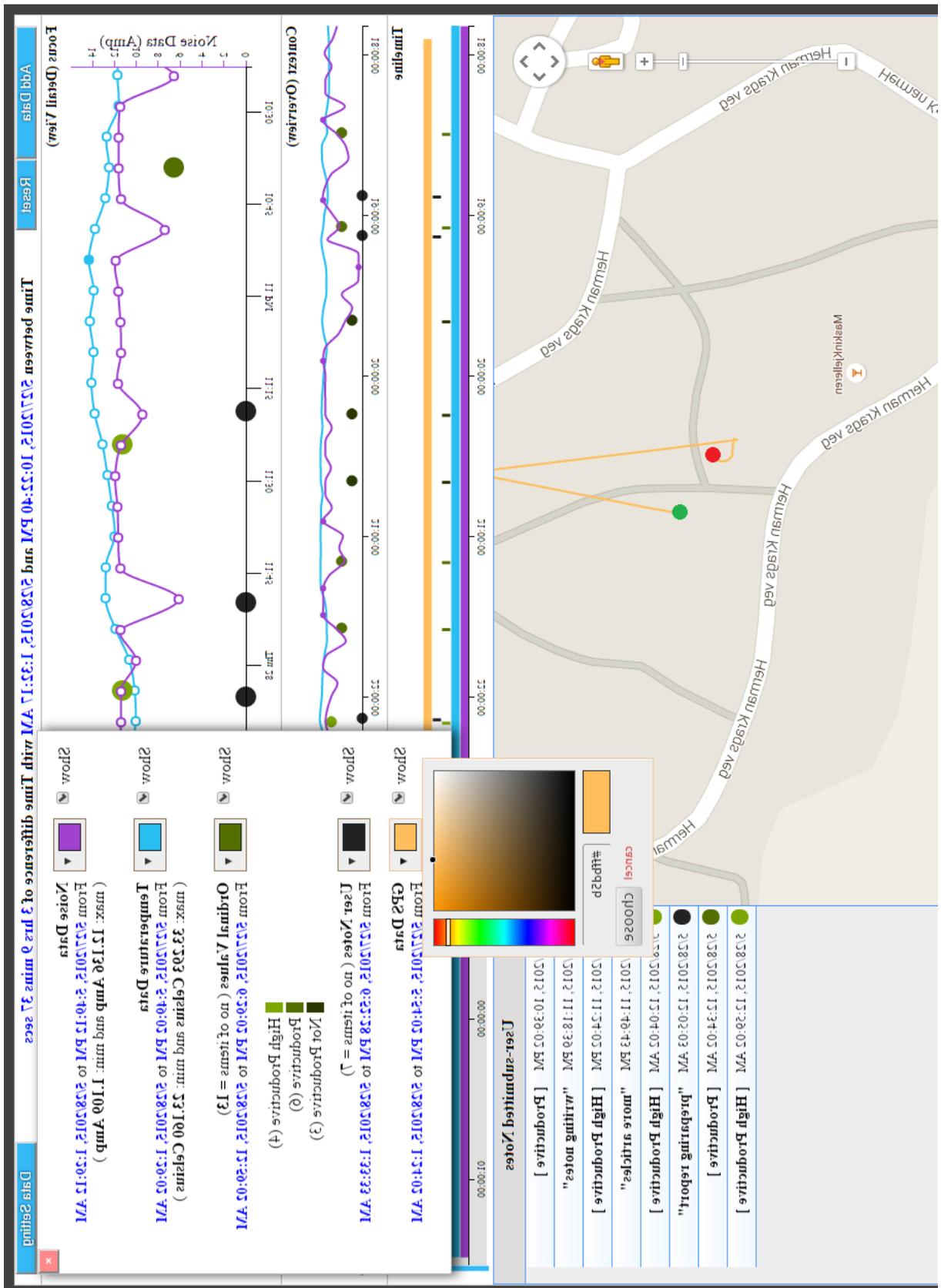**Figure 12 VRL application: Main View with full time-range selection**

Figure 13 VRL application: Data setting - color choosing or data filtering
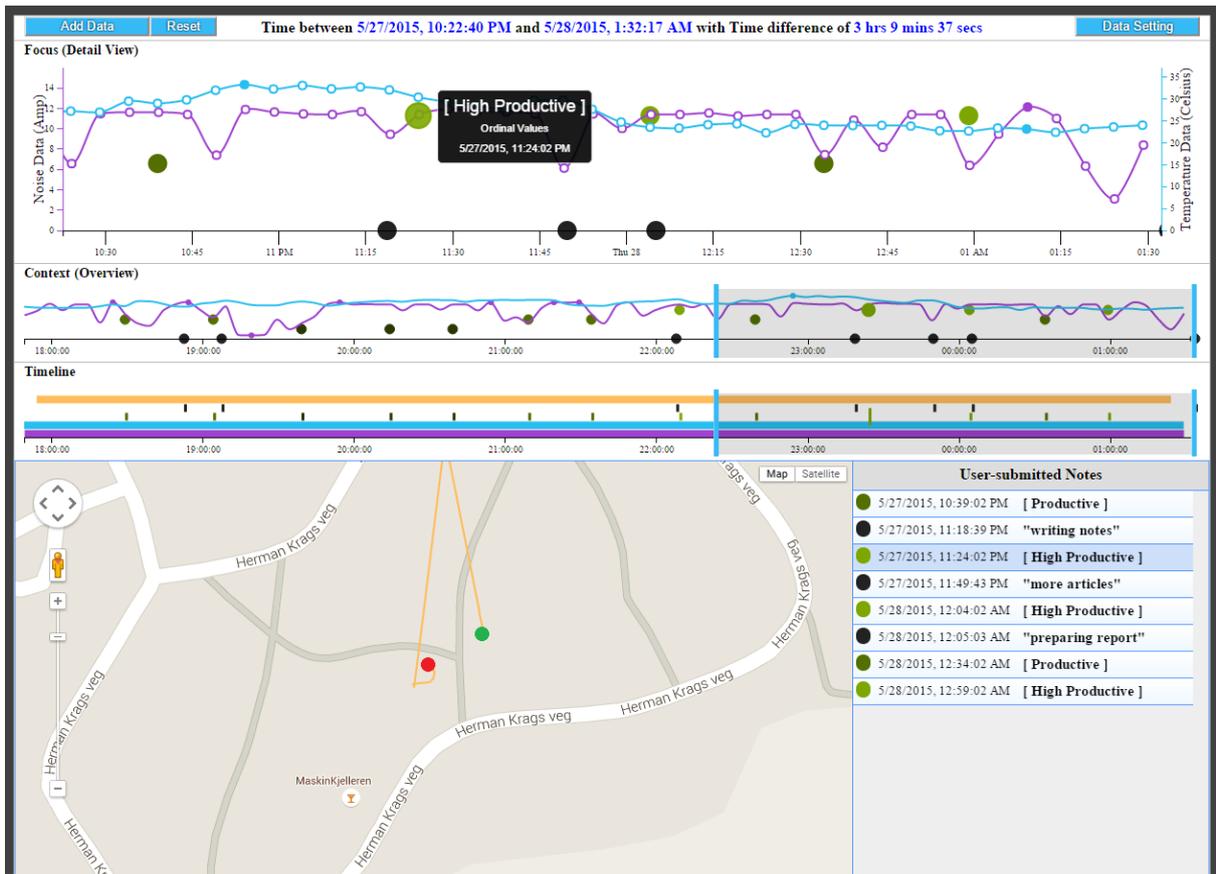
Figure 14 VRL application: Highlight/Tooltip over the ordinal data item

5.3 VRL Data Collection application

The main intention behind this application is to assist the users in collecting data about themselves through their mobile device, and the data it collects would be in the format that the VRL application can readily load. So this application would be rather simple in design.

5.3.1 Requirement Analysis

In this section the requirement analysis for the VRL Data Collection application would be performed.

5.3.1.1 Functional Requirements

Table below describe the functional requirements of the VRL Data Collection Application.

Table 16 VRL Data Collection Application: Functional Requirements

ID	Name	Description
1.	Input nominal data	User can enter nominal texts/notes through the application
2.	Configure ordinal data set	User can set their own ordinal data set e.g. for productivity user can set ordinal dataset with data items like "High Productive", "Medium Productive", "Low Productive"
3.	Input ordinal data item	User can enter ordinal data item from previously configured ordinal data set.
4.	Turn on/off sensor data collection	User can configure to turn on/off the data collection from each of the sensors that the application is capable of (if the feature is added in the application)
5.	Configure data collection interval for each sensor	User can set the interval (each of the sensor) in which the sensor data should be collected
6	Collect sensor data	When the option for data collection is on, the application must collect the data from the respective sensor
7	Save Data	The data from user (nominal and ordinal) and sensors should be saved in the mobile device in the data format defined by VRL application

5.3.1.2 Non-functional Requirements

Non-functional requirements describe how the software performs or works. These requirements are not the specific operations but rather the behaviors through which different operations of the application can be judged.

5.3.1.2.1 Usability

Since the application is only used for collecting user-related data, the application must be easy enough to be used by any type of user. So the user interface must be simple and intuitive.

5.3.1.2.2 Performance

Good performance is the must in any software, so the application being developed must also have a good performance. Each of the user actions must be performed with minimum time lag of about 0.5 seconds or less.

5.3.2 Technological Choices

This section describes on the technological choices made for the VRL Data Collection application.

5.3.2.1 Mobile Platform

The main objective of the VRL Data Collection application is to collect user-related data from the mobile device. According to International Data Corporation (IDC), the mobile device operating market share for 2015 Q1 states that Android OS dominates with 78% followed by iOS with 8.3%. So looking at the statistics it is clear that developing the application for Android and iOS platform would ensure that it would have very high chances of being used by a lot of users. But due to the time constraints for the thesis only Android platform will be the choice for the development of this application.

Table 17 Worldwide Smartphone OS Market Share for 2015 Q1, according to IDC [1]

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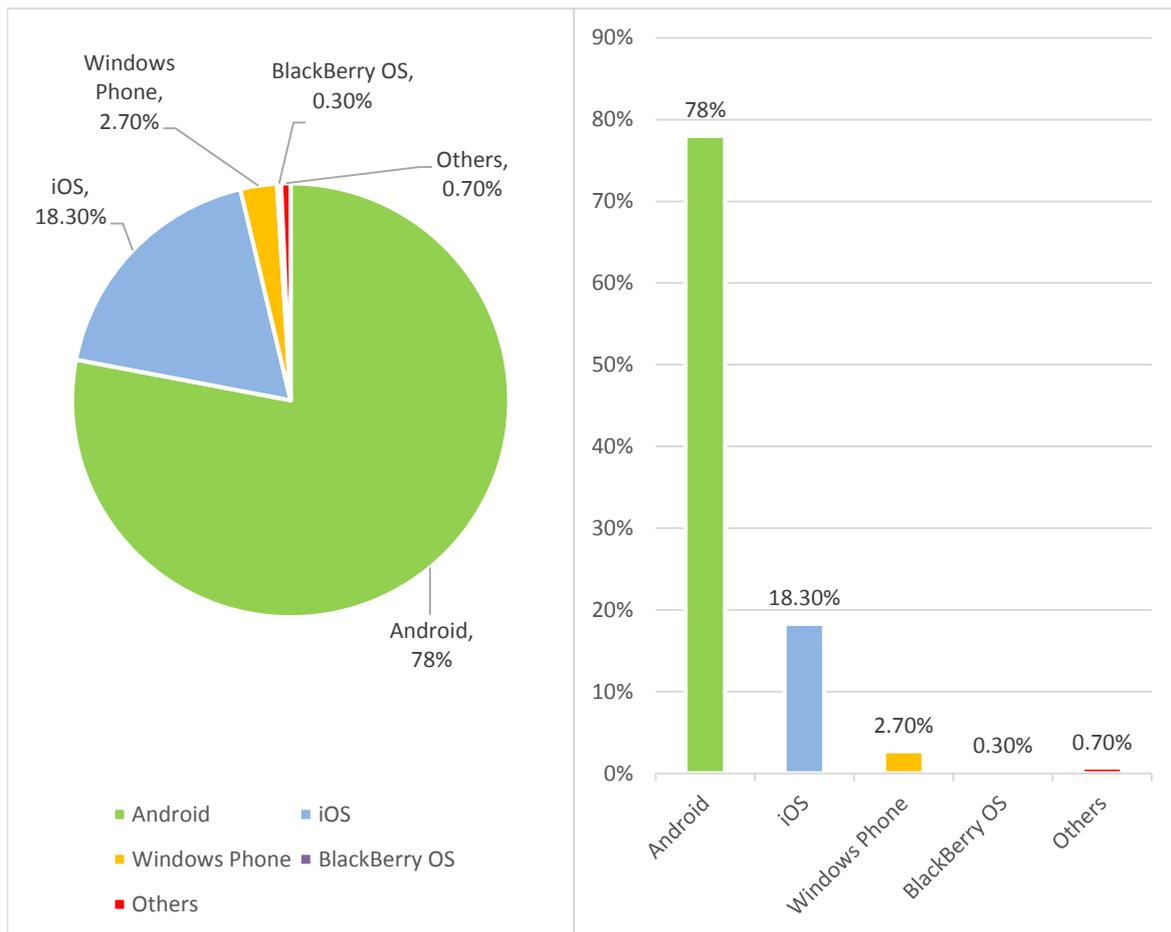
5.3.2.2 Mobile Application Development approach

With the increase in popularity of mobile devices, more and more applications are being developed every day. And because of this, different approach to developing the application for the mobile devices have emerged. Some of the most common approaches are:

5.3.2.2.1 Native

A native application is a specific platform dependent application. Since a native application is platform dependent, they can take advantage of most of the features of the operating system and software installed in that platform. Device specific hardware features like sensors, camera, Bluetooth, etc. can be easily accessed by these application. They are closer or at the fewer layers from the platform than others, and thus computationally quicker providing faster performance if implemented wisely. Because of high performance, they are considered best in providing good user experience.

The limitations of developing this type of application is that, they require a lot more programming, thus more time to develop than others. This makes it expensive to develop, and since the application would only run in one platform, it gets even more expensive if it is needed to build for other platforms since the code cannot be used across platforms. The upgrading or maintenance are also time consuming and costly.

5.3.2.2.2 Mobile Web

Mobile web applications run in the device's web-browser, so they can run across other platforms as well. These types of application are developed using server side programming languages like ASP.NET, PHP, Node.js, etc. along with client-side languages like HTML5, CSS and JavaScript. The cost of developing mobile web applications is relatively very low. These applications are in fact websites, and thus require internet access to run. They have limited access to OS API and cannot access most of the hardware features like sensors, Bluetooth, etc.

5.3.2.2.3 Cross-compiled

In the cross-compiled approach, the application are developed using one programming language and are compiled to the other to make native application for the platform. With this approach the development and the target environments are separated so that the focus stays on the logic and reusability of the code. Since the applications would be deployed as the native application, they can take advantages like full access to functionality of underlying operating system. But these types of development can be complex and difficult because each of the platform have some platform specific approaches to development, and keeping everything consistent in every platform can turn into a lot of work.

5.3.2.2.4 Hybrid

Hybrid application is the combination of native and web applications where the web application is wrapped under a native application. So a hybrid application is integrated to both the device's file system and web-based services. So a hybrid application can take advantages of both the web applications and native applications. Unlike web application which needs internet to function, hybrid application can function without the internet. Since a hybrid application is wrapped under a native application, it is always an abstraction level away from the underlying platform than the native applications, so it is relatively slower than native applications.

5.3.2.2.5 Development Approach for the VRL Data Collection application

VRL Data Collection application needs to collect data from both the user and sensors of the mobile device. So the main requirement for this application is to collect data and be simple to use. To have access to sensors and provide high performance (thus support good user experience), native development approach is chosen. And since the design of the application is very simple, the development time with every other approach would be almost the same so the development time won't be of any concern for this application.

5.3.3 VRL Data Collection application Design mockup

In this section, the mockup design of the VRL Data Collection Application is shown.
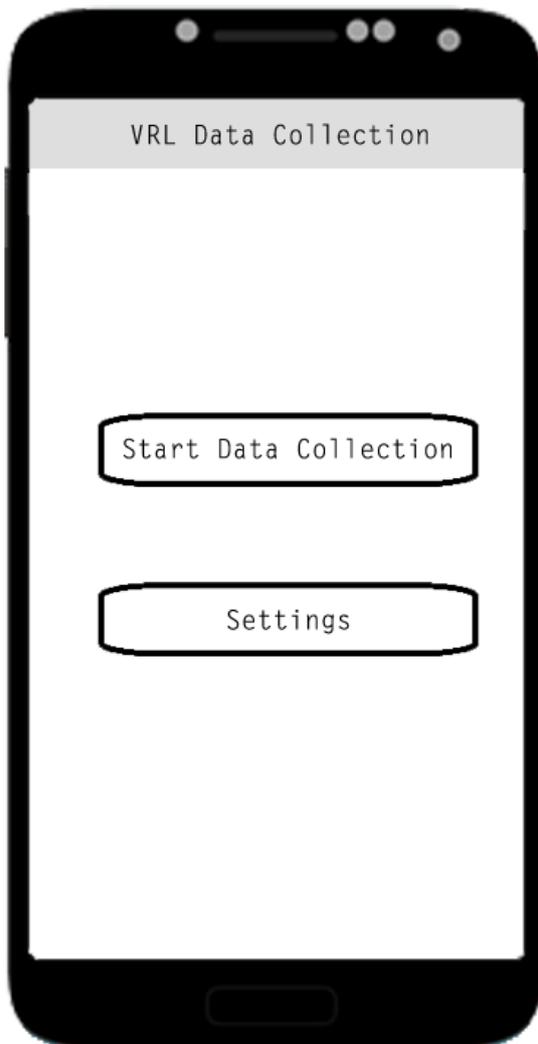

Figure 15 VRL Data Collection application mockup: Main Screen
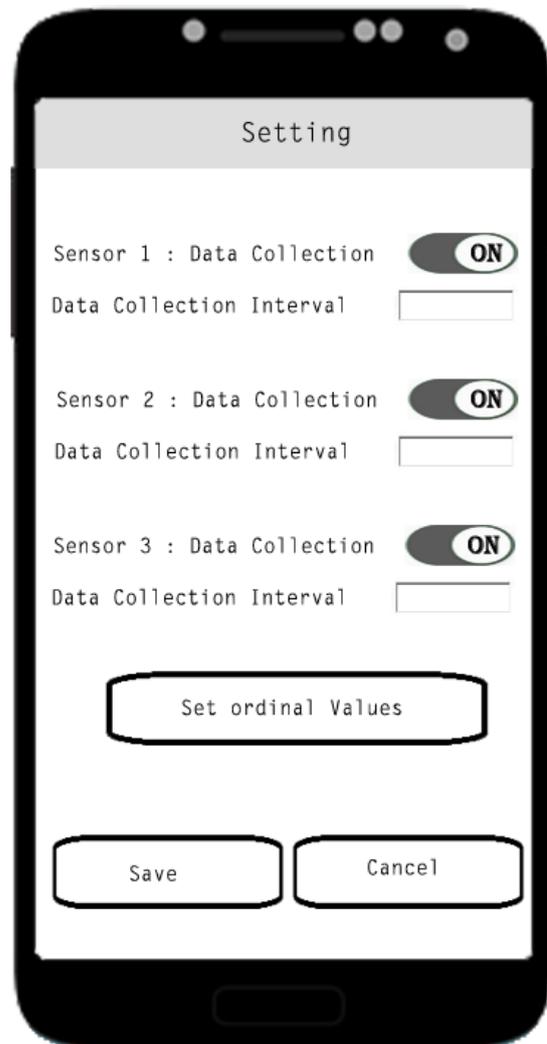
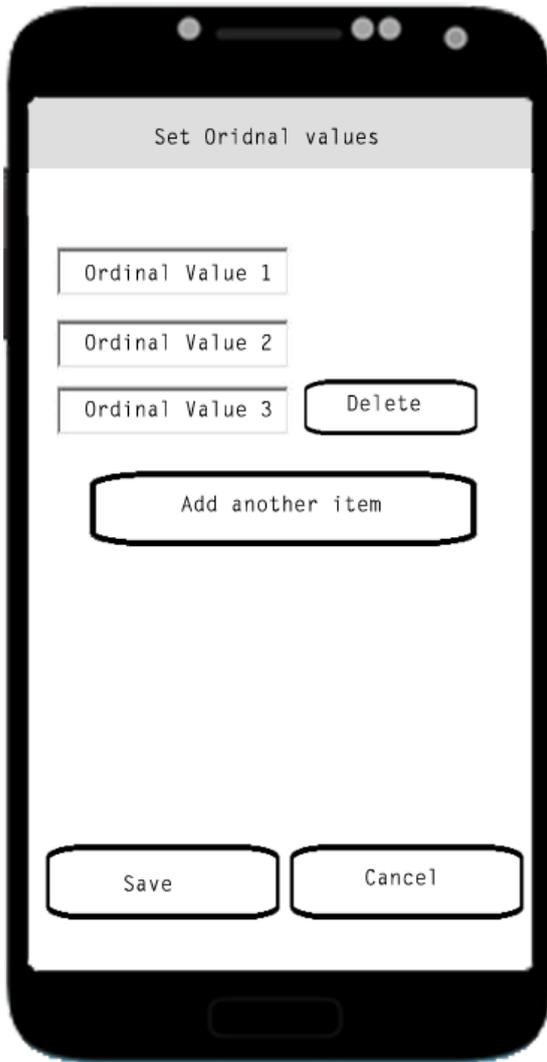**Figure 16 VRL Data Collection application mockup: Settings Screen**

Figure 17 VRL Data Collection application mockup: Set Ordinal Values screen
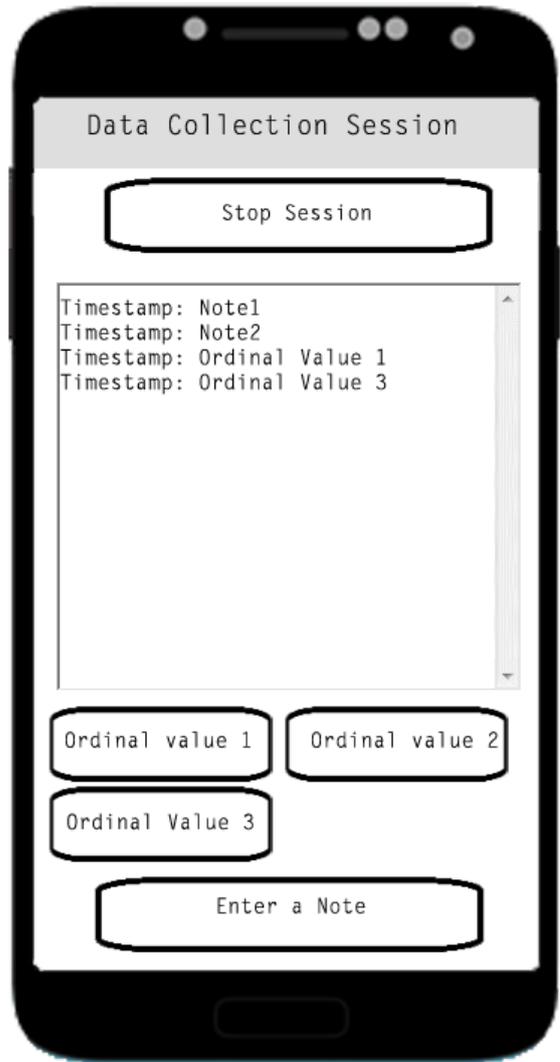
Figure 18 VRL Data Collection application mockup: Data Collection Session screen
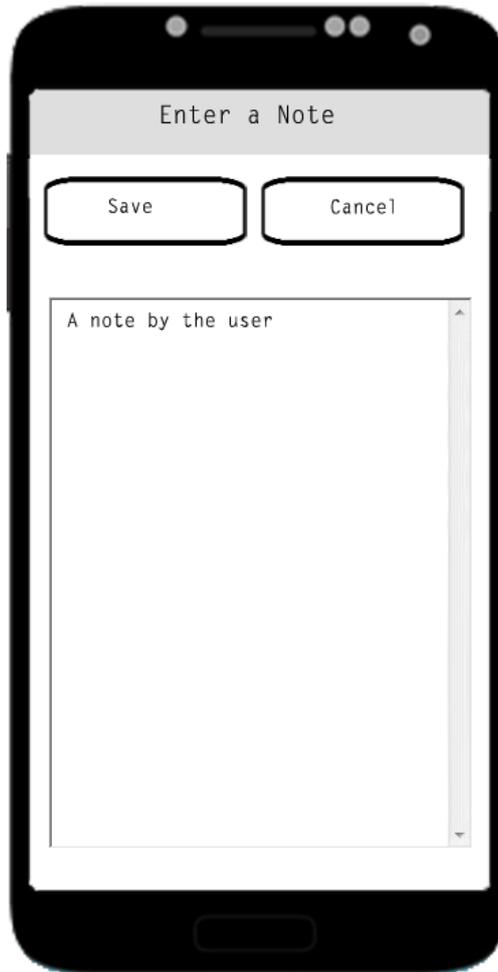
Figure 19 VRL Data Collection application mockup: Enter a Note screen

5.3.4 Use cases

In this sub-section, the use cases for the VRL Data Collection application are presented in the textual form.

Use Case 1: Start data collection session

Purpose	To let the application collect data
Precondition	Application is running and the focus is on the main menu
Step 1	Press 'Start Session' button
Comments	The application would start collecting data from sensors that are turned on and show the interface with options for the user to input ordinal as well as nominal values.

Use Case 2: Input nominal note

Purpose	To let the user input nominal notes
Precondition	Data collection session has been started or is running
Step 1	Press 'Enter a Note' button
Step 2	Input a note in a text-box
Step 3	Press 'Save' button
Comments	User can press 'Cancel' button if they don't want to save the note or go back without writing any note

Use Case 3: Input ordinal data item

Purpose	To let the user use one of the pre-configured ordinal data items
Precondition	Ordinal data collection is on and data collection session is running
Step 1	Press the button with the ordinal data item value
Comments	There would be buttons with ordinal data item values in them, for example, button with text 'High', 'Medium', 'Low', etc.

Use Case 4: Settings page

Purpose	To configure different setting for the application
Precondition	Application is running and the focus is on the main menu
Step 1	Press 'Settings' button
Comments	Press 'Cancel' button come back to main menu

Use Case 5: Turn on/off sensor data and ordinal data collection

Purpose	To let the user turn on or off the data collection for each of the sensors or ordinal data
Precondition	User is at 'Settings' page
Step 1	Press the switch to turn on/off the option for each of the sensors or the switch for ordinal data
Step 2	Press 'Save Setting' button
Comments	Data from each of the sensors whose data collection options are off won't be collected during the data collection session After 'Save Setting' button is pressed, user would be taken to the main menu

Use Case 6: Set data collection time interval for each sensor

|	
Purpose	To change the time interval in which the data is collected for each of the sensors
Precondition	User is at the 'Settings' page
Step 1	Select the interval value for the sensor of choice
Step 2	Change to the different value
Step 3	Press 'Save Setting' button
Comments	The time intervals are in seconds After 'Save Setting' button is pressed, user would be taken to the main menu

Use Case 7: Configure ordinal data set

Purpose	To change the data items in the ordinal data set that can be use during the data collection session
Precondition	User is at the 'Settings' page
Step 1	Press 'Set Ordinal Values' button
Step 2	To add new ordinal data item press 'Add another value' button and enter the value To delete the previously created data item, press 'Delete' button next to the data item To change the value of a data item, just select the data item after which the option to change the value will appear.
Step 2	Press 'Save' button to save the new set of ordinal data items
Comments	Press 'Cancel' button to ignore changes

Use Case 8: Stop the data collection session

Purpose	To stop the application from collecting any more data
Precondition	Data collection session is active or running
Step 1	Press 'Stop Session' button
Comments	The user would be taken to the main menu

5.3.5 Application Screenshots

In this sub-section, the screenshots from the actual application is shown
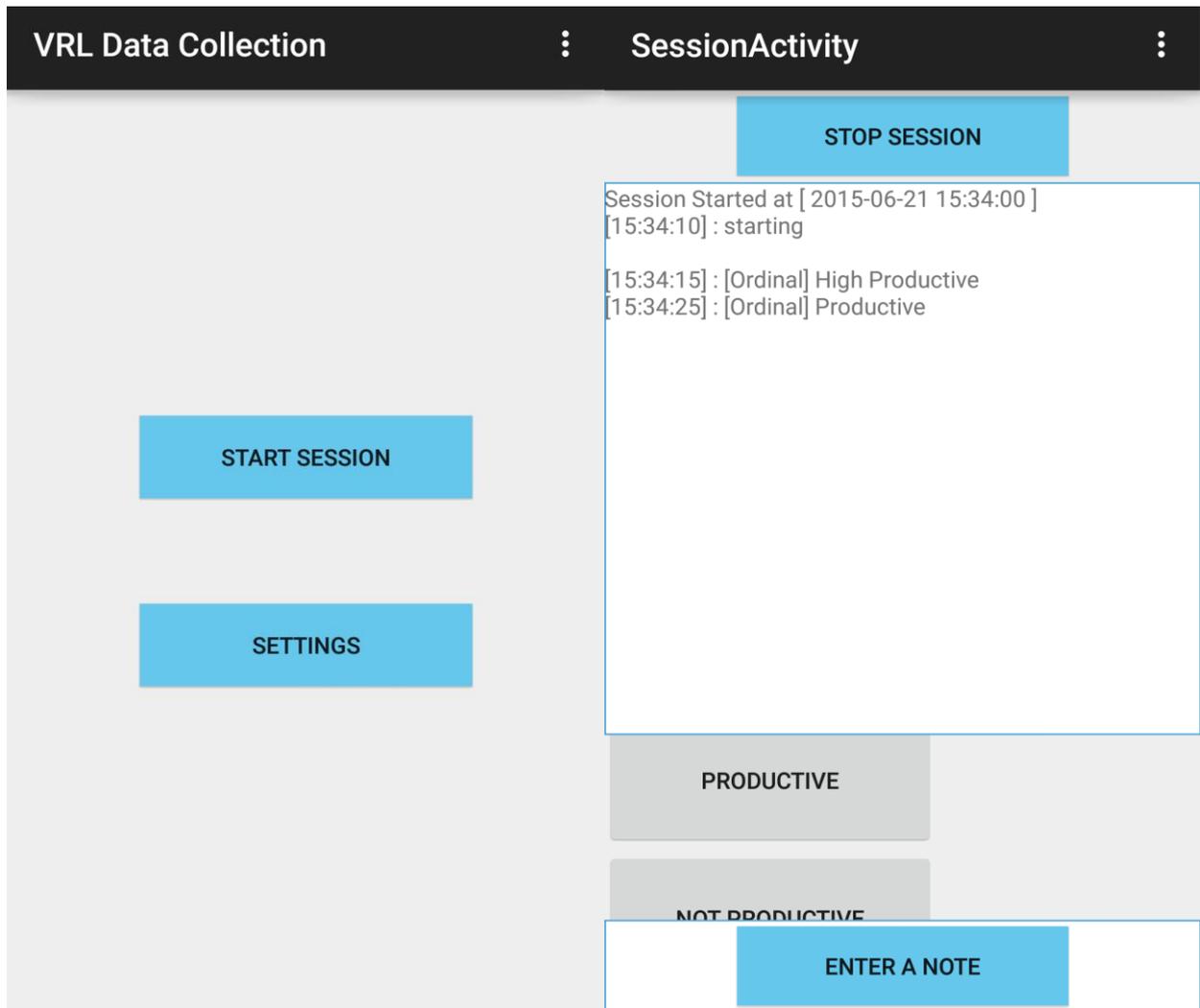
Figure 20 VRL Data Collection application: Main menu

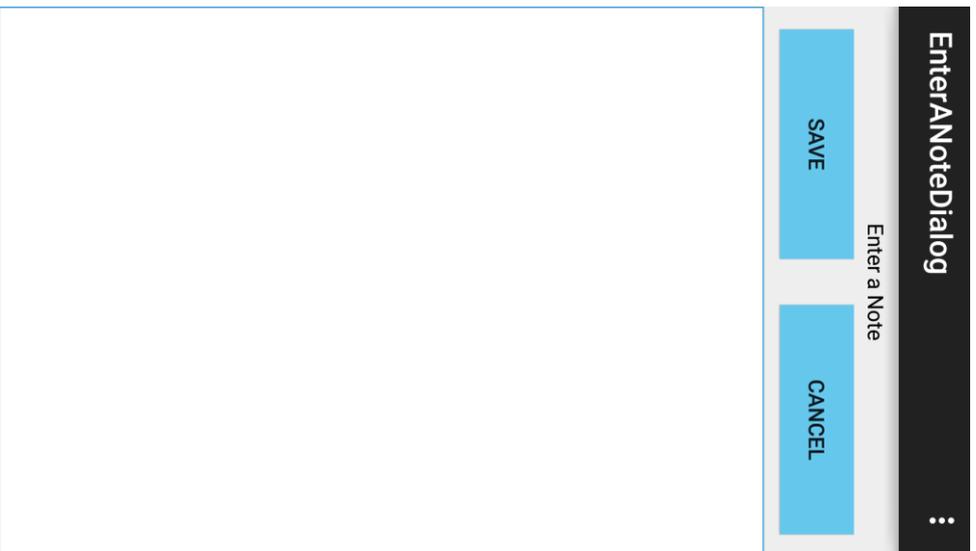**Figure 21 VRL Data Collection Application: Data Collection Session**

EnterANoteDialog ...

Enter a Note

SAVE   CANCEL

Figure 22 VRL Data Collection application:
Screen to enter a nominal note

SettingActivity ...

Settings

GPS Data Collection
GPS data collection interval   600 seconds

Noise Data Collection
Noise data collection interval   300 seconds

Temperature Data Collection
Temperature data collection interval 300 seconds

Ordinal Data Collection
Ordinal Data Collection   SET ORDINAL VALUES

SAVE SETTING   CANCEL

Figure 23 VRL Data Collection application:
Settings screen

OrdinalValuesActivity ...

ADD ANOTHER VALUE

High Productive

Productive

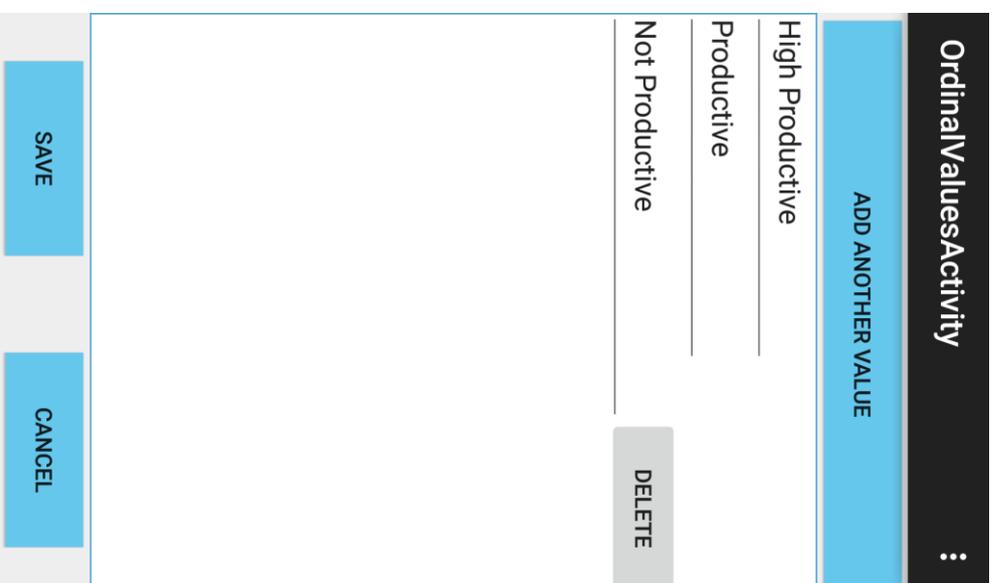Not Productive   DELETE

SAVE   CANCEL

Figure 24 VRL Data Collection application:
Setting for Ordinal data

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6 Evaluation

This chapter explains how the user evaluation for VRL application was conducted, who were the participants, what the evaluation setting was like and what were the results of the evaluation.

6.1 Evaluation Settings

6.1.1 Scenario

The evaluation was based on the first scenario mentioned in section 5.2.1, where a student is collecting information related to his/her productivity in every half hour or every hour. The student would be collecting the ambient noise data of his/her surrounding and keeping notes on what s/he does during the day. The student would use the ordinal notes of 'Very Productive', 'Productive' and 'Not Productive' during the day to track the degree of feeling of productivity at the moment.

6.1.2 Participants

The developed application was evaluated by five students of NTNU. All the students were Master level students on their final semester who were writing their master thesis. The main reason on why only final year Master students participated is that they had free time to use while the students in different level were busy with the preparation for their examinations and so they didn't volunteer to participate. The VRL Data Collection application was developed for the Android platform only, so the number of participants got narrow because of this shortcoming as it was observed that the students carrying mobile devices with iOS platform were equally in large number. Three of the participants were from the Computer Science background, one from Social and Political Science and one from Project Management.

6.1.3 Data for evaluating the Application

The participants were provided with the VRL Data Collection application two to three days earlier than the actual evaluation. This was done to ensure that the participants would be able to collect enough data to be used in the application during the actual evaluation.

Based on the scenario 1 previously described, the participants were told to collect their productivity related data during their studying time. Participants were told to input productivity based ordinal values like "Highly productive", "Productive" or "Not Productive" during the time they were studying. Similarly they were told to write notes about their

feelings and/or activities during the data collection session. Participants were also told to collect GPS, ambient noise and ambient temperature data through the application.

All the participants were explained and instructed on how to use the VRL Data Collection application. Since the application is very simple and straightforward, it was observed that all the participants understood how to operate the application very quickly.

6.1.4 Actual Evaluation: Procedure

The actual evaluation was conducted on one of the meeting rooms in the IT department of NTNU which was reserved for the whole day. A video camera was setup to capture the actual evaluation process for the reference later. One laptop, connected with an extra larger monitor, was used for evaluating the application where the application was preinstalled and was ready for the evaluation. The application was evaluated by each of the participants separately. For each participant, the total time spend for using the application, interview, and filling up the questionnaires took from forty minutes to an hour of time.

At first, the participants were asked to sign the 'Consent for Participation' contract. This was to reassure the participants that they had the full right to leave the evaluation process if they feel uncomfortable, by any chance, during the evaluation process, and also to ensure that the participants understood that the evaluation process was formal and was getting video recorded.

After signing the 'Consent for Participation' contract, data collected from the 'VRL Data Collection' application was copied to the laptop where the application was installed. Then the participants were given an instruction sheet where instructions were given on what to do. From this point onwards, the evaluation process was video recorded.

When the participants finished using the application based on the instruction sheet, they were given some time to spend on exploring their data in the application by themselves. Then the interview was conducted which lasted for five to ten minutes. After the interview, the participants were given to fill up three questionnaires. One questionnaire was related to 'VRL Application' as a whole, another about Usability specific to it and the third one was the standard SUS (System Usability Scale) questionnaire. The evaluation ended when the participants filled up the questionnaires.

6.1.5 Questionnaires

First questionnaire, which was about the VRL application as a whole, consisted of 12 questions relating to reflection, learning, and visualization and interaction techniques used in it. The questions were based on five-level Likert scale to get the participant's feedback on perceived usefulness of the application and its features on those topics. Question 3 and 4 were

related to reflection due to the application, question 5 and 6 were related to learning due to the application, question 7 and 8 were related to conscious decision or plans influenced by the application, question 1, 2, 10 and 11 were about the usefulness of visualization techniques used in the application, question 9 was about the usefulness of automatically collected sensor data in the reflection process, and question 12 was about the overall usefulness of visualization and interaction techniques in understanding the data.

Second questionnaire, which was about the usability specific to the VRL application, consisted of 8 questions and was also based on five-level Likert scale. It was used to get the feedback on perceived easiness on using each of the interaction techniques used in the application.

Third questionnaire was the standard System Usability Scale (SUS) questionnaire developed by John Brookes for understanding the usability of the system from a higher-level subjective view [102]. The questionnaire has ten general questions relating to the usability of the system.

6.2 Results

6.2.1 Reflection

It was found that the application seemed useful for the participants to reflect on their experiences (3.8, SD = 0.74) [Questionnaire 1: Question 3]. All participants eagerly looked into their data. Some of them even started explaining what they were doing at a certain point looking at the data-points in the application.

On the question, if the frequent use of the application can help the participant to reflect more in the future, participants agreed that the application would be of help for reflecting (3.8, SD = 0.74) [Questionnaire 1: Question 4].
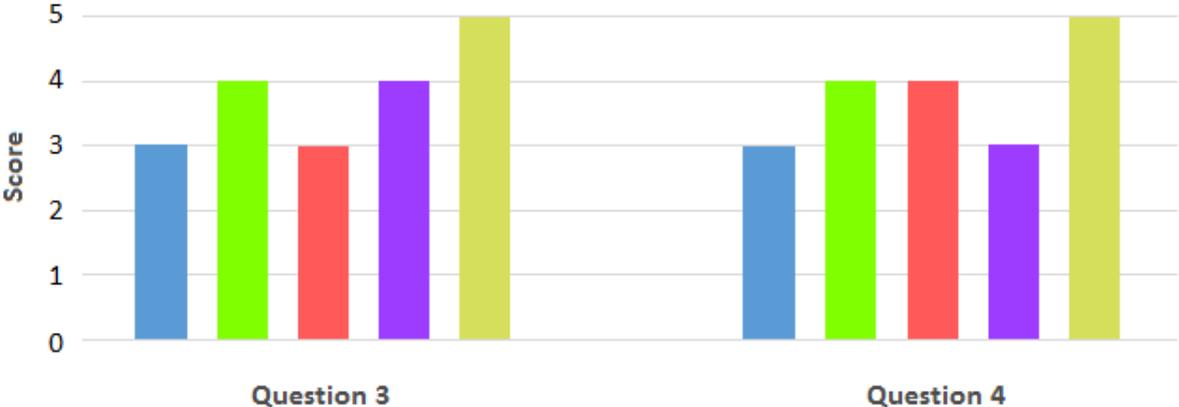

Figure 25 Results on reflection through the application

6.2.2 Learning

It was found that the participants learned something about their experience through the application (3.4, SD = 1.01) [Questionnaire 1: Question 5]. On the question, if the frequent use will help the participant to understand their work life much better, the results were a little higher than previous question (3.8, SD = 0.74) [Questionnaire 1: Question 6]. So it can be said that, the participants were a little more optimistic on being able to learn from the application on the frequent use.
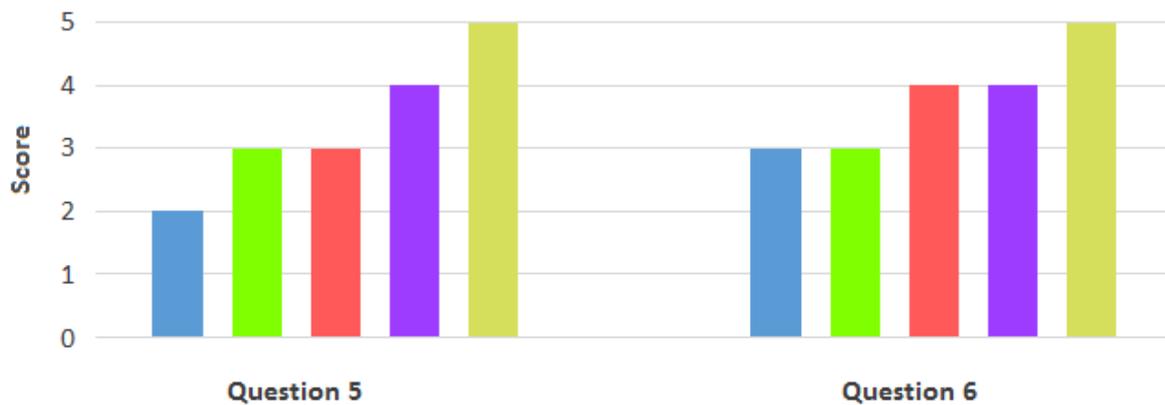

Figure 26 Results on learning through the application

The results showed that the learning from the application had led the participants to come up with some new decisions or plans to follow in the future (3.2, SP = 1.16) [Questionnaire 1: Question 7]. The participants were optimistic on the use of application to change or improve upon their work life or behaviors with the frequent use (4, SP = 0.63) [Questionnaire 1: Question 8].
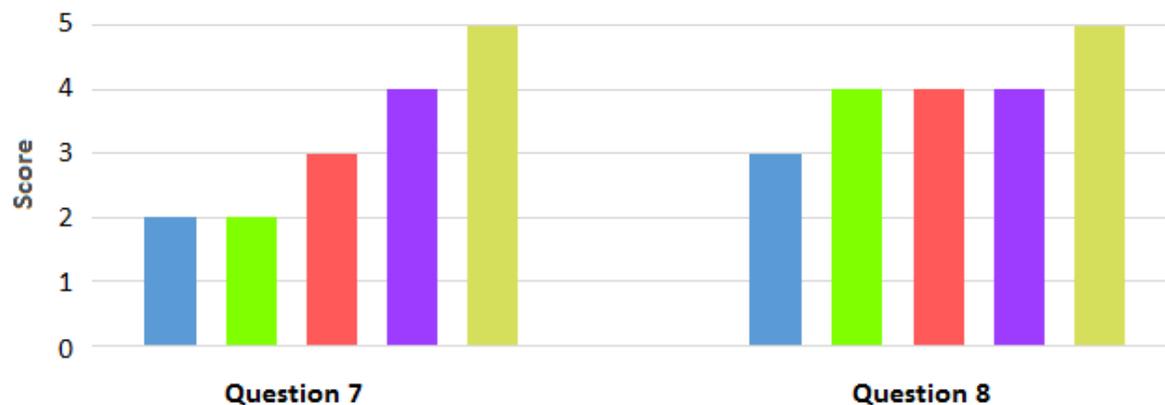

Figure 27 Result on plan for changes in future through the application

6.2.3 Visualization Techniques

It was found that the use of 'Focus+Context' visualization approach served well to the participants in exploring their data (4.4, SD = 0.48) [Questionnaire 1: Question 1]. Almost all the participants agreed that after spending some time with the application, they could understand which charts/panels were 'focus' views and which were 'context' views.

Similarly, participants agreed that the use of 'Multiple representation' visualization technique also helped them to understand their data easily (4.4, SD = 0.8) [Questionnaire 1: Question 2]. Most of the participants commented that the charts/panels were very intuitive and they could easily see how each charts/panel presented the same data.
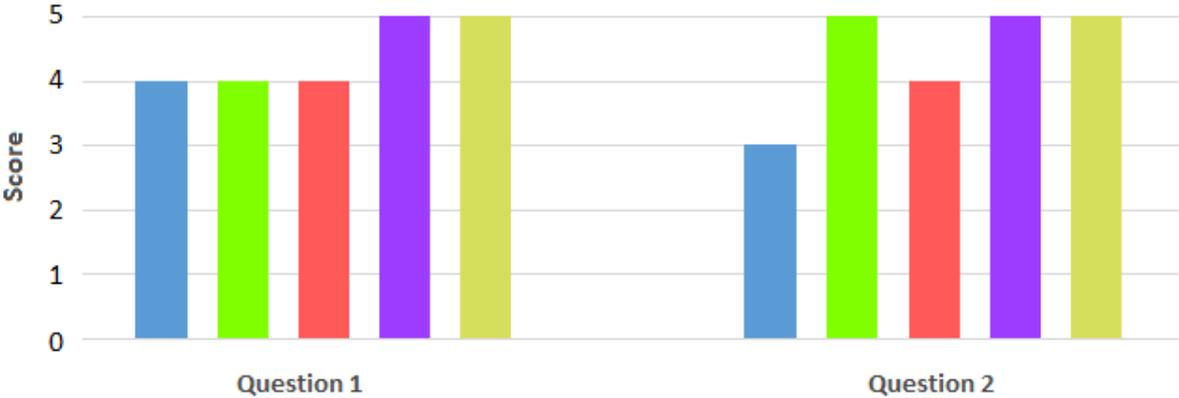

Figure 28 Result on Visualization techniques

It was found that the 'Color consistency' for each of the data all across the charts/panels was a very helpful feature that the participants thought made their experience with the application much easier (4.6, SP = 0.48) [Questionnaire 1: Question 10].

Participants thought that the 'ordinal placement of the ordinal values' was a very helpful visualization technique to grab the information more easily from the application (4.8, SP = 0.4) [Questionnaire 1: Question 11]. Most of the participants commented that this feature was very useful as they could instantly see and figure out their own working patterns.
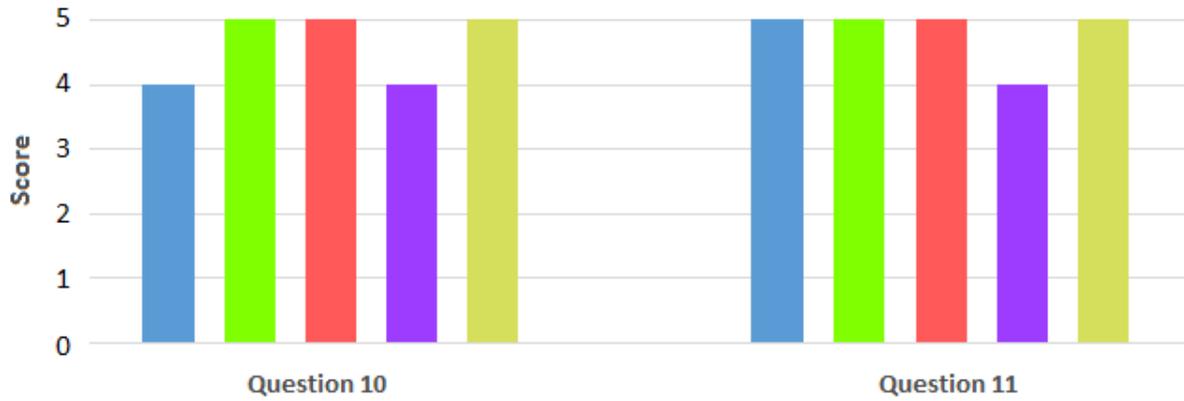
Figure 29 Results on Visualization techniques

6.2.4 User Interaction Techniques

It was found that all the interaction techniques employed in the application were very much of help to the participants. Participants expressed their opinions on interaction techniques in the interview. All the interaction techniques received good feedback from all the participants and none of the participants expressed any negative opinions on any of them.

6.2.5 Usability

First usability questionnaire was very specific to the application's features, mostly, the easiness to use the interaction techniques employed by the application. High value (equal to and above 80 percent) tells that that the participants found the interaction techniques easy to use.
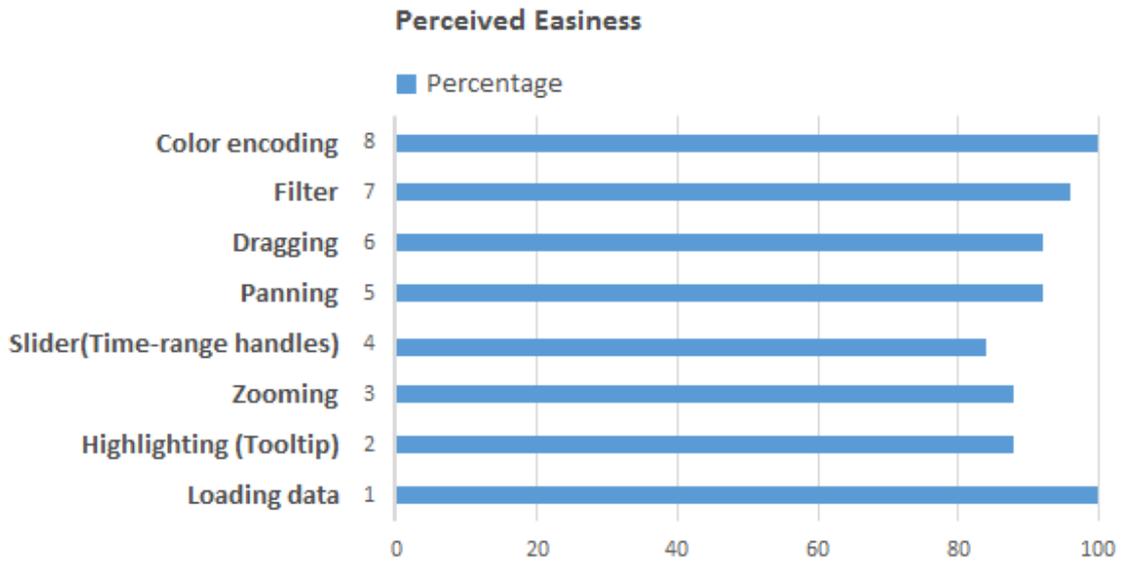
Perceived Easiness

Figure 30 Perceived easiness in using the application

The System Usability Scale (SUS) questionnaire yielded average score of 85 points which is considered a good score [103]. Actually, score from and above 80 has been generally considered to denote a good usability of the system [104]. With participants from different fields of study but not just the Computer Science, the good usability score can be taken as a good sign for the application. But taking into consideration that there were only five participants, it may not be enough to guarantee that the system is really good in terms of usability.
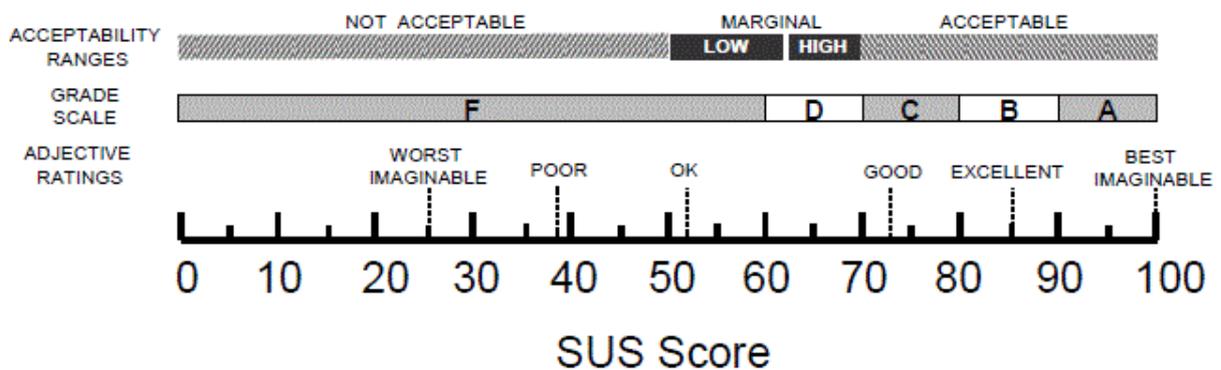

Figure 31 SUS Scale : Determining what Individual SUS Scores Mean: Adding Adjective Rating Scale [104]
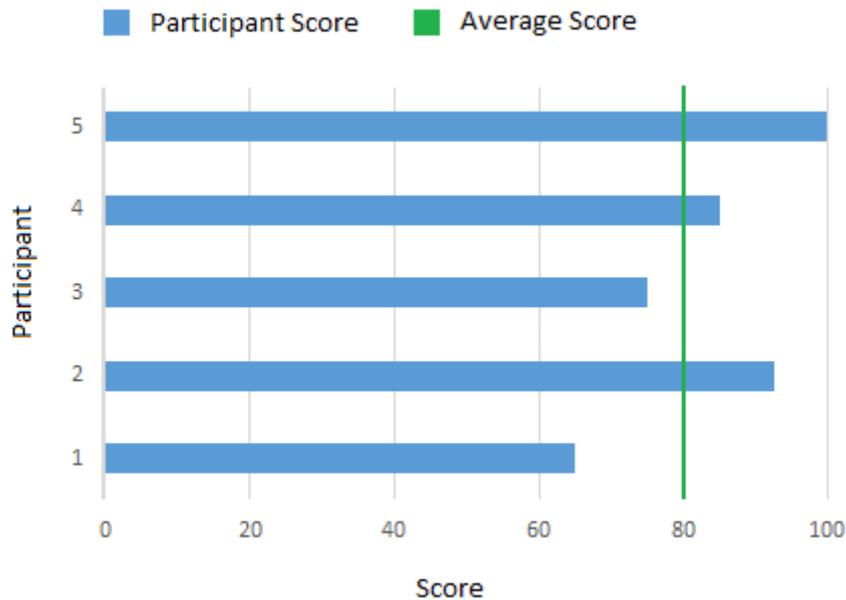
Figure 32 System Usability Scale (SUS) Score for VRL application

6.2.6 Technical Issues

The technical issues were only noticed or mentioned about the 'VRL Data Collection' application. Some of the participants mentioned that there had been some data loss as they couldn't see the notes they had written down or ordinal values they had entered in the application. The cause of the problem could lie in the 'VRL Data Collection' application, it being the android application that had only been tested in three different smartphones. The participants were carrying android smartphones from different brands and with different android versions. Even though the tests performed on the virtual emulators and the actual smartphones were showing no such problems before, there could still be some bugs specific to some smartphone models or android version because of huge android fragmentation and the fact that the development time for the application was very short. The other reasons could be that the participants may have accidentally stopped the application instance and opened up a new instance, in which case, the previous data were not written to the file.

The other technical issue was relating to the GPS data. One of the participants forgot to turn on the GPS on his smartphone while collecting data because of which he didn't have the location data to be used in the main VRL application. Because of this, the participant could not get to have the complete experience of viewing his entire data on the VRL application.

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6.3 Discussion

This section presents the discussion on the result of the evaluation and discusses on if they help answer the research questions.

6.3.1 Research Questions

6.3.1.1 Sub RQ-1

Which visualization techniques are suitable for visualizing sensor data and user-submitted data?

From the results of the evaluation, we found that all the visualization techniques applied in the application showed good results. These visualization techniques were selected after analyzing the types of data and the visualization challenges they posed. All selected visualization techniques, namely 'Focus+Context', 'Multiple representation', 'Color consistency', 'Emphasize/Connect' and 'Ordinal placement of ordinal values' are suitable for visualizing sensor data and user-submitted data.

Focus+Context Visualization technique

Some of the participants expressed their opinion on Focus+Context visualization techniques in the interview. Three of the participants mentioned that they liked 'Focus+Context' approach, and they mentioned that it was very helpful technique for exploring their data.

"Each panel[charts] give you clear idea… on what you expect to see"

"I guess it is the optimal way of representation"

"[All charts] works very well"

Focus (Detail View) chart and Context (Overview) chart

In the application, both 'Focus (Detail View)' and 'Context (Overview)' charts were used to visualize the combination of continuous data and user-submitted data. Some of the participants mentioned that they liked these charts

"I really like the Focus (Detail View) chart, Context (Overview) is equally important."

"Focus (Detail View) chart was the best"

For the combination of continuous and user-submitted data, 'Line chart' turn out to be a good visualization technique where user-submitted data (nominal and ordinal values) were depicted as colored circles sharing the same x-axis with the continuous data. Showing combination of different data made it easier for the user to figure out any correlation between them.

"[Line charts served as] one of the ways to investigate your stress related problem…

…you can easily see if it was caused by the noise from here [line chart]"

Timeline Chart

A timeline chart was found to be a good approach to visualize all the data together based on the time they were created and/or based on the time they started and ended. In the application, keeping x-axis as the time, user-submitted data (nominal and ordinal) were shown as the lines or ticks showing when they were created. Continuous data and geo-location data were shown as lines with starting point to show when the data was started to be recorded and the ending point to show when the data was stopped recording.

Two participants mentioned that the 'Timeline' chart seemed redundant.

"There is time everywhere, it is not very helpful"

But their opinion changed when they were explained a scenario where it could be used. The scenario was about filtering the location based on a certain time-range. When they realized that the location data was also being displayed as a straight line in the 'Timeline' chart, they understood the meaning of it. They instantly understood that they could filter the path in the 'Map' chart by selecting a certain time-range in the 'Timeline' chart. They changed their opinion about 'Timeline' chart when they had this realization.

"Oh, now it makes sense"

But one of the participant still insisted that it was still not very important. His argument was that the 'Timeline' chart could be, somehow, combined with 'Context (Overview)' chart and there was no absolute importance to keep it separate.

Color consistency visualization technique

Color consistency visualization technique turn out to be very useful. Most of the participants rated high on it and none of them struggled in recognizing the data. One participant mentioned 'Color consistency' exclusively and explained that the feature served really well.

"[Color consistency was helpful as it was easier with] colors to distinguish between the different data"

Emphasize/Connect visualization technique

It was found that the participants were able to distinguish each data in different charts because of the emphasize technique. One participant mentioned 'emphasize/connect' visualization technique and commented that it was very useful.

"I see you can hover and emphasize [the data] ...

... you hover to emphasize,... and this makes sense"

Ordinal placement of the Ordinal Values visualization technique

The ordinal values shown in different heights (placement based on their order) is found to be a good technique to visualize ordinal values. Two of the participants exclusively mentioned that the 'ordinal placement of the ordinal values' was very helpful to them.

"... the ordinal placement was very helpful to understand how my days have been"

They mentioned that it was a really good technique and served very well to understand the data more easily.

One of the participants mentioned that there should be the option to change the order (ascending or descending) and also the height gaps between the data, the feature application lacked.

Maps Chart

Geo-location data can be shown in a map as data points. In the application, the geo-location data within the selected time-range were shown as the path line in the map representing the path taken by the user during that time frame. To make it easier to identify the start and the end of the path, the start of the path line was shown as a green circle and the end of the path as a red circle. All participants thought it was necessary to have the 'Map' chart.

"[the Map] it doesn't get any better than that."

One of the participant mentioned that the Map chart was fine, but there should be some mechanism to filter the data based on the selection in the map, the feature the application lacked.

User Notes Panel

For the quick glimpse or for detailed information on the user-submitted data, a dedicated panel can be used to show all those data. In the application, 'User Notes' panel was used to show the user-submitted data where all the notes, within the selected time-range, were displayed in chronological order. This way the user can easily see every notes at a glimpse without having to interact with the data point in any other charts. Most of the participants liked the 'User Notes' panel. Two participants mentioned that the 'Notes' panel should have the toggle show and hide option to allow the 'Map' chart to be shown wider when felt needed because they thought 'User Notes' panel was not very important.

"Notes panel did not get my attention at first"

One participant mentioned that he preferred to look at the 'User Notes' panel to look for the ordinal and nominal values.

"I was always looking at notes panel for notes."

But one of the participants mentioned that he never felt the need for the 'User Notes' panel as he could see the values by highlighting the data in the 'Focus (Detail View)' chart.

Verdict

With the good feedback and scores through the questionnaires, we can see that the employed visualization techniques, namely "Focus+Context", "Multiple representation", "Color consistency", "Emphasize/Connect" and "Ordinal placement of Ordinal data" are good visualization techniques for visualizing sensor data and user-submitted data.

6.3.1.2 Sub RQ-2

Which user interaction techniques provide good user experience for exploring and extracting information from data through the visualizations?

Looking at the results of the evaluation, we found that all the interaction techniques applied in the application showed good results. From the results of questionnaire on perceived easiness in using the interaction techniques, all seven different types of interaction techniques applied in the application received good scores. The least value was 84% which in itself is a good score.

Out of five participants, two of the participants were not given instruction on how to use the different interaction techniques before the evaluation and three of them were given the instructions.

Highlight/Tooltip

Even when two of the participants were not given the instruction on how to use the different interaction techniques, all of the participants figured out where the 'Highlighting/tooltip' worked. All the participants were hovering around the data to see the tooltip and it seemed it was driven by the intuition to expect highlighting to work. During the interview, four of the participants were very quick to mention that they found 'highlighting (tooltip)' very helpful.

"I think the most useful was highlighting… I can see a lot with hover [highlighting]"

"Highlighting was very nice", "Highlighting was very helpful"

But two of the participants mentioned that the 'Highlighting/tooltip' was good but it also needed to work in 'Notes Panel' and 'Context (Overview)' chart, the feature the application lacked.

Zooming

Both the participants, who were not given the instruction on how to use the different interaction techniques, were not able to figure out that the application supported 'Zooming' feature. Rest of the participants were given instructions before the evaluation and they were comfortable in using it. One participants, exclusively, mentioned 'Zooming' to be very helpful.

"I think the zooming is convenient"

One participant mentioned that zooming was working fine, but he would preferred 'Dragging' and 'Slider' because he felt more in control with them than with the 'Zooming'.

"... zooming is not very predictable. This [slider and dragging] is more predictable as I have more control over the range "

Panning

None of the participants specifically mentioned 'Panning' to be their favorite interaction technique. But it was found that all the participants who were given the instructions used it. They all seemed to be comfortable with the technique, and looking at the results with 92 percent score, we can say that it was overall a useful interaction technique.

But one participant mentioned that he never used 'Panning' and may not use it because it was much easier to use 'Dragging'.

Dragging

All the participants who received the instruction before the evaluation used the dragging technique comfortably. Those who did not receive the instructions before evaluation, were provided with the instructions right before the interview and allowed to explore their data again. Three of the participant mentioned that they really liked dragging interaction technique.

"I liked dragging… to focus on some certain periods"

"Dragging was really helpful"

"I prefer dragging from the Context (Overview) [chart]"

Slider (Time-range handles)

It was found that all the participant were comfortable on using 'Slider' after the instructions (before evaluation for three participants and before interview for two participants). Everyone who mentioned they liked 'Dragging' were also mentioning to like 'Slider'.

Filter

It was observed that all the participants used the 'Filter' technique to show/hide the data comfortably. None of the participants specifically mentioned it anytime, but looking at the very good score of 96 percentage in easiness to use, we can say that the participants overlooked its importance. Another reason can be that, none of the participants had a lot of data that crammed any charts/panels so the participants must not have seen its importance.

Color encoding

It was observed that all the participants used the 'Color encoding' technique at least once to change the color of the data. None of the participants mentioned this interaction technique. But it scored the perfect 100 percent score in the easiness of use. This can also be taken as participants overlooking its importance. It was pre-programmed to assign different unique color to each new data loaded in the application. This could be the reason that the participants never had any confusion identifying each of the data based on the color.

Verdict

With good reviews from the interviews and the questionnaires, we can say that zooming, panning, dragging, slider (or time-range handles), filter, highlighting (or tooltip) and color encoding are some of the good user-interaction techniques for exploring and extracting information from the data though the identified visualizations.

6.3.1.3 Main RQ:

Does the use of visualization and user-interaction techniques to visualize and interact with the user-submitted data and sensor data also promote reflective learning?

Looking at the results of the evaluation and answers to sub-research questions, we can see that the application that was developed based on visualization and user-interaction techniques was able to help the users in reflecting about their experiences and also learn something from it.

But, since the evaluation was conducted by very few participants, and basing on such a small group, it cannot be strongly argued that the research question has been answered. More evaluations needs to be conducted to be sure that the claim has been proved.

But still, looking at the result, it can at least be said that the result shows promise on use of visualization and user-interaction techniques as yet another way towards promoting reflective learning.

7 Conclusion

This chapter will present the summary of the thesis and finally presents the future works that can be done as the continuation to this thesis.

7.1 Summary

This thesis examined on the use of visualization and interaction techniques to support reflective learning in user based on the data about the user themselves. This was done by evaluating the application (VRL) that was developed based on different visualization and interaction techniques for visualizing and interacting with different user-related data. Another mobile application (VRL Data Collection) was also developed to assist the user in collecting different types of data about themselves.

Nowadays it is much easier for people to collect data about themselves. Many researches have be done towards using these data for health related tasks or for improving well-being of users, but very few have taken reflective learning approach. Investigating through related works, it was found that very few have taken the visualization and interaction approach towards reflective learning with these user-related data (user-submitted data and sensor-data related to user), and none of them focused on both of these user-submitted data and sensor data.

Two scenarios were identified where the users are interested in using the data collected from their actual experience for finding answers to different question related those experiences. Analyzing the different types of user-related data that can be collected, and analyzing the two scenarios with CSRL model, four high level requirements for the application (VRL) was identified: support for different types of data, proper visualization and interaction techniques, support for reflection, and good user-experience/usability. The VRL application was developed to achieve all these requirements.

By analyzing the scenarios and user-related data, different visualization and interaction challenges were identified which were also related to the high level requirements. With the help of related works and theories on visualization and interaction, the analysis of these challenges were done to come up with different visualization and interaction techniques to be used in the application.

The VRL application was evaluated by five participants who collected data about themselves using VRL Data Collection application for at least two days. All the participants were

students working on their master thesis and the data collected by them were about their productivity. The results of the evaluation was found to be positive. However, it was evaluated by very few participants so further evaluation needs to be conducted to confirm the results. And because of the limited time, the development of the application was limited to a simpler prototype. This needs to be a longitudinal study where the application needs to be developed further and evaluated multiple times to find out if what it claim to support is really true.

7.2 Future Work

The main target of this thesis was to find out if visualization and interaction techniques for visualizing and interacting with user-related data can promote reflective learning in the user. Even though the results from the evaluation was positive, there are some limitations and features needed in the application.

User-submitted nominal data can take many other forms and not just textual form, like voice/sound, pictures/snapshots/photos, video clips, etc. This has been ignored in the categorization process and so not considered while analyzing the visualizations to be used in the application. Further works can be done in integrating them into the visualizations.

User-submitted data (both ordinal and nominal) were presented as circles in the Focus (Detail View) and Context (Overview) charts, and the only way users could customize them was by changing their color. Some participants mentioned about the feature of allowing the users to change the symbol shape or using different icons for that. This can be the part of future work.

In the application, there were only two types of filtering possible. One was filtering among the data by showing or hiding them. Other was by filtering the data based on the time-range. Further works can be done in adding different types of filters, like filtering based on the location, etc.

To see the patterns in data, data collected in different sessions can be visualized on the same chart where they are stacked on top of each other. This can allow us to see if there is any type of regularities or irregularities present. The application do not have this feature yet and thus can be the future work.

Adding support for group reflection and providing features to compare data among user can be the future works.

Use of animations with the visualization can be explored to see if they can further aid in the reflection process.

8 References

1. *Smartphone Operating System market share for 2015 Q1*. 2015 [cited 2015 2015-06-21]; Available from: http://www.idc.com/prodserv/smartphone-os-market-share.jsp.
2. Boud, D., R. Keogh, and D. Walker, *Reflection: Turning experience into learning*. 2013: Routledge.
3. Atzori, L., A. Iera, and G. Morabito, *The Internet of Things: A survey.* Computer Networks, 2010. **54**(15): p. 2787-2805.
4. Chui, M., M. Löffler, and R. Roberts, *The internet of things.* McKinsey Quarterly, 2010. **2**(2010): p. 1-9.
5. Lane, N.D., et al., *A survey of mobile phone sensing.* Communications Magazine, IEEE, 2010. **48**(9): p. 140-150.
6. Truillet, P., *A Taxonomy of Physical Contextual Sensors*, in *Human-Computer Interaction. Interaction Platforms and Techniques*, J. Jacko, Editor. 2007, Springer Berlin Heidelberg. p. 982-989.
7. Gaggioli, A., et al., *A mobile data collection platform for mental health research.* Personal and Ubiquitous Computing, 2013. **17**(2): p. 241-251.
8. Spence, R., *Information Visualization: Design for Interaction (2nd Edition)*. 2007: Prentice-Hall, Inc.
9. *Readings in information visualization: using vision to think*. ed. K.C. Stuart, D.M. Jock, and S. Ben. 1999, Morgan Kaufmann Publishers Inc. 686.
10. Ji Soo, Y., et al., *Toward a Deeper Understanding of the Role of Interaction in Information Visualization.* Visualization and Computer Graphics, IEEE Transactions on, 2007. **13**(6): p. 1224-1231.
11. Dix, A. and G. Ellis. *Starting simple: adding value to static visualisation through simple interaction*. in *Proceedings of the working conference on Advanced visual interfaces*. 1998. ACM.
12. Zhicheng, L. and J.T. Stasko, *Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective.* Visualization and Computer Graphics, IEEE Transactions on, 2010. **16**(6): p. 999-1008.
13. Card, S.K., J.D. Mackinlay, and B. Shneiderman, *Readings in information visualization: using vision to think*. 1999: Morgan Kaufmann.
14. *The MIT License (MIT)*. 2015 [cited 2015 2015/07/03]; Available from: http://opensource.org/licenses/MIT.
15. Rai, P.C., *Visualizing WATCHiT data for Reflective Learning*. 2014, Norwegian University of Science and Technology.
16. Dewey, J., *How We Think*. 1926: D.C. Heath & Company.
17. Prilla, M., M. Degeling, and T. Herrmann, *Collaborative reflection at work: supporting informal learning at a healthcare workplace*, in *Proceedings of the 17th ACM international conference on Supporting group work*. 2012, ACM: Sanibel Island, Florida, USA. p. 55-64.
18. Moon, J.A., *A Handbook of Reflective and Experiential Learning: Theory and Practice*. 2013: Taylor & Francis.
19. Johns, C., *The value of reflective practice for nursing.* Journal of Clinical Nursing, 1995. **4**(1): p. 23-30.
20. Wilkinson, J., *Implementing reflective practice.* Nursing Standard, 1999. **13**(21): p. 36-40.
21. Kolb, D.A., *Experiential Learning: Experience As the Source of Learning and Development*. 1984: Pearson Education.

22. Kolb, D.A. and R.E. Fry, *Toward an Applied Theory of Experiential Learning*. 1974: M.I.T. Alfred P. Sloan School of Management.

23. Schön, D.A., *The Reflective Practitioner: How Professionals Think in Action*. 1983: Basic Books.

24. Lin, X., et al., *Designing technology to support reflection.* Educational Technology Research and Development, 1999. **47**(3): p. 43-62.

25. Krogstie, B. and M. Divitini. *Supporting reflection in software development with everyday working tools*. in *Proceedings of the 9th International Conference on the Design of Cooperative Systems (COOP)*. 2010.

26. Xiao, L., et al. *Promoting reflective thinking in collaborative learning activities*. in *Advanced Learning Technologies, 2008. ICALT'08. Eighth IEEE International Conference on*. 2008. IEEE.

27. Krogstie, B., M. Prilla, and V. Pammer, *Understanding and Supporting Reflective Learning Processes in the Workplace: The CSRL Model*, in *Scaling up Learning for Sustained Impact*, D. Hernández-Leo, et al., Editors. 2013, Springer Berlin Heidelberg. p. 151-164.

28. Ward, M.O., G. Grinstein, and D. Keim, *Interactive Data Visualization: Foundations, Techniques, and Applications*. 2010: Taylor & Francis.

29. Gershon, N., S.G. Eick, and S. Card, *Information visualization.* interactions, 1998. **5**(2): p. 9-15.

30. Larkin, J.H. and H.A. Simon, *Why a Diagram is (Sometimes) Worth Ten Thousand Words.* Cognitive Science, 1987. **11**(1): p. 65-100.

31. Anscombe, F.J., *Graphs in statistical analysis.* The American Statistician, 1973. **27**(1): p. 17-21.

32. Festinger, L., *A theory of cognitive dissonance*. Vol. 2. 1962: Stanford university press.

33. Consolvo, S., D.W. McDonald, and J.A. Landay, *Theory-driven design strategies for technologies that support behavior change in everyday life*, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2009, ACM: Boston, MA, USA. p. 405-414.

34. Glahn, C., M. Specht, and R. Koper, *Supporting reflection in informal learning.* 2008.

35. Govaerts, S., et al., *Visualizing Activities for Self-reflection and Awareness*, in *Advances in Web-Based Learning – ICWL 2010*, X. Luo, et al., Editors. 2010, Springer Berlin Heidelberg. p. 91-100.

36. Whittaker, S., et al., *Socio-technical lifelogging: deriving design principles for a future proof digital past.* Human–Computer Interaction, 2012. **27**(1-2): p. 37-62.

37. Muller, W. and H. Schumann. *Visualization methods for time-dependent data - an overview*. in *Simulation Conference, 2003. Proceedings of the 2003 Winter*. 2003.

38. Few, S., *Information Dashboard Design: The Effective Visual Communication of Data*. 2006: O'Reilly Media, Incorporated.

39. Heer, J., M. Bostock, and V. Ogievetsky, *A tour through the visualization zoo.* Commun. ACM, 2010. **53**(6): p. 59-67.

40. Jelen, B., *Charts and Graphs: Microsoft Excel 2010*. 2010: Que Publishing.

41. Horrigan, S., *Visualizing Relationships among Categorical Variables.*

42. Few, S., *Quantitative vs. Categorical Data; A Difference Worth Knowing.* Information Management, 2005. **15**(4): p. 42.

43. Herman, I., G. Melancon, and M.S. Marshall, *Graph visualization and navigation in information visualization: A survey.* Visualization and Computer Graphics, IEEE Transactions on, 2000. **6**(1): p. 24-43.

44.	Scherr, M., *Multiple and coordinated views in information visualization.* Trends in Information Visualization. **38**.

45.	Eick, S.G., *Data visualization sliders*, in *Proceedings of the 7th annual ACM symposium on User interface software and technology*. 1994, ACM: Marina del Rey, California, USA. p. 119-120.

46.	van Wijk, J.J. and W.A.A. Nuij. *Smooth and efficient zooming and panning*. in *Information Visualization, 2003. INFOVIS 2003. IEEE Symposium on*. 2003.

47.	Cockburn, A., A. Karlson, and B.B. Bederson, *A review of overview+ detail, zooming, and focus+ context interfaces.* ACM Computing Surveys (CSUR), 2008. **41**(1): p. 2.

48.	Yuk, M. and S. Diamond, *Data Visualization For Dummies*. 2014: Wiley.

49.	Cellan-Jones, R. *A 15 pound computer to inspire young programmers*. 2011 2015/06/09]; Available from: http://www.bbc.co.uk/blogs/thereporters/rorycellanjones/2011/05/a_15_computer_to_inspire_young.html.

50.	Foundation, R.P. *Raspberry Pi*. 2015 2015/06/09]; Available from: https://www.raspberrypi.org/.

51.	Arduino. *Arduino*. 2015 2015/06/09]; Available from: http://www.arduino.cc/en/guide/introduction.

52.	Richter, C. *Visualizing sensor data*. in *Media Informatics Advanced Seminar on Information Visualization*. 2009.

53.	Zankl, S., *Visualizing Sensor Data.* Trends in Information Visualization: p. 61.

54.	Rodriguez, C.G. and A.-M. Déry-Pinna, *Visualizing Sensor Data: Towards an Experiment and Validation Platform*, in *Human-Centered Software Engineering*, M. Winckler, P. Forbrig, and R. Bernhaupt, Editors. 2012, Springer Berlin Heidelberg. p. 352-359.

55.	Larson, R. and M. Csikszentmihalyi, *The experience sampling method*, in *New Directions for Methodology of Social and Behavioral Science*. 1983. p. 41-56.

56.	Riediger, M., *Experience sampling.* 2009.

57.	Intille, S., C. Kukla, and X. Ma. *Eliciting user preferences using image-based experience sampling and reflection*. in *CHI'02 Extended Abstracts on Human Factors in Computing Systems*. 2002. ACM.

58.	MIT. *Context-Aware Experience Sampling* 2008 [cited 2015-06-10; Available from: http://web.mit.edu/caesproject/.

59.	Muukkonen, H., et al., *Process-and context-sensitive research on academic knowledge practices: developing CASS-tools and methods*, in *Proceedings of the 8th iternational conference on Computer supported collaborative learning*. 2007, International Society of the Learning Sciences: New Brunswick, New Jersey, USA. p. 545-547.

60.	Shiffman, S., A.A. Stone, and M.R. Hufford, *Ecological Momentary Assessment.* Annual Review of Clinical Psychology, 2008. **4**(1): p. 1-32.

61.	Reis, H.T. and C.M. Judd, *Handbook of Research Methods in Social and Personality Psychology*. 2000: Cambridge University Press.

62.	Lachmann, H., et al., *Introducing and adapting a novel method for investigating learning experiences in clinical learning environments.* Informatics for health and social care, 2012. **37**(3): p. 125-140.

63.	Muukkonen, H., et al., *CASS-methods and tools for investigating higher education knowledge practices*, in *Proceedings of the 8th international conference on International conference for the learning sciences - Volume 2*. 2008, International Society of the Learning Sciences: Utrecht, The Netherlands. p. 107-114.

64.	Seitamaa-Hakkarainen, P., et al., *Materiality and emotions in making.* Techne Series-Research in Sloyd Education and Craft Science A, 2013. **20**(3).

65.   Falin, P., *Augmented Paper Diary Method for capturing the aesthetic experience in Ceramic Practice.*

66.   Lachmann, H., et al., *Promoting reflection by using contextual activity sampling: a study on students' interprofessional learning.* Journal of interprofessional care, 2014. **28**(5): p. 400-406.

67.   *Personal Informatics.* 2014   [cited 2014 2015/06/11]; Available from: http://www.personalinformatics.org/.

68.   *"The Quantified Self".* 2015   [cited 2015 2015/06/11]; Available from: http://quantifiedself.com/about/.

69.   Regalado, A. *Stephen Wolfram on Personal Analytics.* 2014 [cited 2015 2015/06/11]; Available from: http://www.technologyreview.com/news/514356/stephen-wolfram-on-personal-analytics/.

70.   Li, I., A. Dey, and J. Forlizzi. *A stage-based model of personal informatics systems.* in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* 2010. ACM.

71.   Li, I., A.K. Dey, and J. Forlizzi, *Understanding my data, myself: supporting self-reflection with ubicomp technologies*, in *Proceedings of the 13th international conference on Ubiquitous computing.* 2011, ACM: Beijing, China. p. 405-414.

72.   Rivera-Pelayo, V., et al., *A framework for applying quantified self approaches to support reflective learning.* Mobile Learning, 2012.

73.   Ver, et al., *Live interest meter: learning from quantified feedback in mass lectures*, in *Proceedings of the Third International Conference on Learning Analytics and Knowledge.* 2013, ACM: Leuven, Belgium. p. 23-27.

74.   Pommeranz, A., et al., *Self-reflection on personal values to support value-sensitive design*, in *Proceedings of the 25th BCS Conference on Human-Computer Interaction.* 2011, British Computer Society: Newcastle-upon-Tyne, United Kingdom. p. 491-496.

75.   Garcia, J.J., et al., *ESTHER 1.3: integrating in-situ prompts to trigger self-reflection of physical activity in knowledge workers*, in *Proceedings of the 2013 Chilean Conference on Human - Computer Interaction.* 2013, ACM: Temuco, Chile. p. 1-4.

76.   Garcia, J., et al., *Designing Personal Informatics for Self-reflection and Self-awareness: The Case of Children with Attention Deficit Hyperactivity Disorder*, in *Ambient Intelligence*, J. Augusto, et al., Editors. 2013, Springer International Publishing. p. 109-123.

77.   Pirzadeh, A., L. He, and E. Stolterman, *Personal informatics and reflection: a critical examination of the nature of reflection*, in *CHI '13 Extended Abstracts on Human Factors in Computing Systems.* 2013, ACM: Paris, France. p. 1979-1988.

78.   Mamykina, L., et al., *MAHI: investigation of social scaffolding for reflective thinking in diabetes management*, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* 2008, ACM: Florence, Italy. p. 477-486.

79.   Patel, R.A., et al., *Probing the benefits of real-time tracking during cancer care.* AMIA Annual Symposium Proceedings, 2012. **2012**: p. 1340-1349.

80.   Santos, J.L., et al., *Goal-oriented visualizations of activity tracking: a case study with engineering students*, in *Proceedings of the 2nd International Conference on Learning Analytics and Knowledge.* 2012, ACM: Vancouver, British Columbia, Canada. p. 143-152.

81.   Govaerts, S., et al., *The student activity meter for awareness and self-reflection*, in *CHI '12 Extended Abstracts on Human Factors in Computing Systems.* 2012, ACM: Austin, Texas, USA. p. 869-884.

82. Mathur, P. and K. Karahalios. *Using bookmark visualizations for self-reflection and navigation*. in *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. 2009. ACM.

83. Sharmin, M. and B.P. Bailey, *ReflectionSpace: an interactive visualization tool for supporting reflection-<i>on</i>-action in design*, in *Proceedings of the 9th ACM Conference on Creativity & Cognition*. 2013, ACM: Sydney, Australia. p. 83-92.

84. Zhao, O.J., T. Ng, and D. Cosley. *No forests without trees: particulars and patterns in visualizing personal communication*. in *Proceedings of the 2012 iConference*. 2012. ACM.

85. Gr, E., et al., *Understanding challenges and opportunities of preventive blood pressure self-monitoring at home*, in *Proceedings of the 31st European Conference on Cognitive Ergonomics*. 2013, ACM: Toulouse, France. p. 1-10.

86. Durall, E. and T. Toikkanen, *Feeler: feel good and learn better.* Awareness and Reflection in Technology Enhanced Learning: p. 83.

87. Cuttone, A., M.K. Petersen, and J.E. Larsen, *Four Data Visualization Heuristics to Facilitate Reflection in Personal Informatics*, in *Universal Access in Human-Computer Interaction. Design for All and Accessibility Practice*. 2014, Springer. p. 541-552.

88. Meyer, J., et al., *From Visualization to Visually Enabled Reasoning.*

89. Pike, W.A., et al., *The science of interaction.* Information Visualization, 2009. **8**(4): p. 263-274.

90. Shneiderman, B. *The eyes have it: a task by data type taxonomy for information visualizations*. in *Visual Languages, 1996. Proceedings., IEEE Symposium on*. 1996.

91. Ed Huai-Hsin, C. and J.T. Riedl. *An operator interaction framework for visualization systems*. in *Information Visualization, 1998. Proceedings. IEEE Symposium on*. 1998.

92. Sarkar, M. and M.H. Brown, *Graphical fisheye views.*

93. Sarkar, M., et al. *Stretching the rubber sheet: a metaphor for viewing large layouts on small screens*. in *Proceedings of the 6th annual ACM symposium on User interface software and technology*. 1993. ACM.

94. Rao, R. and S.K. Card. *The table lens: merging graphical and symbolic representations in an interactive focus+ context visualization for tabular information*. in *Proceedings of the SIGCHI conference on Human factors in computing systems*. 1994. ACM.

95. Robertson, G.G. and J.D. Mackinlay. *The document lens*. in *Proceedings of the 6th annual ACM symposium on User interface software and technology*. 1993. ACM.

96. Robertson, G.G., J.D. Mackinlay, and S.K. Card. *Cone trees: animated 3D visualizations of hierarchical information*. in *Proceedings of the SIGCHI conference on Human factors in computing systems*. 1991. ACM.

97. *Tooltip*. 2015 [cited 2015 2015/06/14]; Available from: http://techterms.com/definition/tooltip.

98. Bostock, M., V. Ogievetsky, and J. Heer, *D³ Data-Driven Documents.* Visualization and Computer Graphics, IEEE Transactions on, 2011. **17**(12): p. 2301-2309.

99. *Processing*. 2015 [cited 2015 2015/06/22]; Available from: https://processing.org/.

100. Tilkov, S. and S. Vinoski, *Node.js: Using JavaScript to Build High-Performance Network Programs.* Internet Computing, IEEE, 2010. **14**(6): p. 80-83.

101. *Model-View-Controller* 2015 [cited 2015 2015-06-26]; Available from: https://msdn.microsoft.com/en-us/library/ff649643.aspx.

102. Jordan, P.W., et al., *Usability Evaluation In Industry*. 1996: Taylor & Francis.

103.   Sauro, J. *Measuring Usability With The System Usability Scale (SUS)*. 2015 2015-06-06]; Available from: http://www.measuringu.com/sus.php.

104.   Bangor, A., *Determining what individual SUS scores mean: Adding an adjective rating scale.* Journal of usability studies, 2009. **4**(3): p. 114-123.

Appendices

A: Consent for participation in a Software evaluation

I volunteer to participate in the evaluation of software developed by Pawan Chamling Rai, MSc. In Information Systems student, of NTNU for his master thesis.

I give Pawan permission to video record the entire evaluation process and use the data for his master thesis. I allow him to take written notes during the evaluation process. If at any point of time I do not want to continue, I have the full right to withdraw from the participation.

I have been given a copy of this consent form co-signed by researcher (Pawan).

_____   _____

Participant's Signature   Date

_____   _____

Researcher's Signature   Date

B: Questionnaire: VRL application

Answer on a scale from 1-5 (1 being "Strongly Disagree" and 5 being "Strongly agree")

	Strongly Disagree			Strongly Agree	
	1	2	3	4	5
1. The 'Focus+Context' visualization approach in the VRL application made it easier for me to explore the data.	☐	☐	☐	☐	☐
2. The 'multiple representation' visualization technique in the VRL application helped me to extract different types of information from the same data.	☐	☐	☐	☐	☐
3. The VRL application helped me to reflect on my experiences.	☐	☐	☐	☐	☐
4. I think the frequent use of the VRL application will help me in reflecting on my past experiences.	☐	☐	☐	☐	☐
5. Using the VRL application, I was able to understand something new about my work life.	☐	☐	☐	☐	☐
6. I think the frequent use of the VRL application will help me to understand my work life more.	☐	☐	☐	☐	☐
7. Using the VRL application, it helped me to come up with new decision or plan to follow in my future experiences.	☐	☐	☐	☐	☐
8. I think the frequent use of the VRL application will help me to come up with decisions or plans to change or improve my future experiences.	☐	☐	☐	☐	☐
9. The automatically collected sensor data helped me to understand or reflect on my experience more.	☐	☐	☐	☐	☐
10. The color consistency for each of the data in all the charts and panels within the application made the whole experience easier for me.	☐	☐	☐	☐	☐
11. The placement of Ordinal values in different heights (based on the order of the value) in the Focus and Context charts helped me to grab the information more easily.	☐	☐	☐	☐	☐

12. Visualization and Interaction techniques in the VRL application has helped me to gain more information from the data than it would have been without the use these techniques.

☐ ☐ ☐ ☐ ☐

C: System Usability Scale

System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

D: Interview Questions

1. Do you think each of the charts or panels in the application are serving well to give you information?
    a. What do you think about their placement?
    b. Do you have any suggestion on their placement?
2. Do you think there could be some more visualization charts or panels to make the experience better?
    a. What are your suggestions?
3. Do you think one or more of the charts/panel are unnecessary?
    a. If yes, which one and why?
4. Which of the features in the application, do you think, helped you the most in understanding the data? Which feature do you like the most?
    a. The different charts
        i. If yes, which one
    b. The different interaction techniques
        i. If yes, which one
5. Did you see anything inconsistent in the application?
6. Do you have any suggestions how to make the application better to help you reflect on your experiences so that you can learn something from it?