

GUIDELINES FOR DESIGNING PERSONAL HEALTH DASHBOARDS

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ABSTRACT

The healthcare industry is realising the value of providing ordinary individuals with their personal health data for self-care and self-management purposes, however, these individuals are faced with the challenge of going through, understanding and extracting insights from large volumes of complex personal health data. A dashboard (coupled with data visualization) is regarded as a suitable way to present personal health data effectively, to inform self-care and self-management-based decisions. However, there is no homogeneous (i.e. “one-size-fits-all”) approach to designing dashboards; therefore, this research aimed at creating a set of design guidelines that can be used as a foundation for tailoring dashboards that support the presentation of personal health data.

The Design Science Research methodology was used to systematically develop and evaluate the set of dashboard design guidelines. Within this methodology, literature was reviewed and focus groups with participants were conducted to extract insights and inform the development of the initial set (proposed) design guidelines. The proposed design guidelines were then used to develop a medium-fidelity personal health dashboard prototype. Usability testing with the dashboard prototype was conducted to evaluate the efficacy and utility of these design guidelines. The evaluation provided insights that strengthened the quality of the design guidelines. The evaluation indicated that the proposed set of guidelines are suitable for designing a dashboard that presents personal health data effectively. These design guidelines can be adapted in order to inform the process of tailoring dashboards for accommodating different personal health data presentation needs.

KEYWORDS: Dashboards; Visualization; Personal Health Data; Self-care; Self-management; Digital Health; Design Guidelines.

DECLARATION

I, **Chabana Chabana**, hereby declare that:

- The work in this thesis is my own work.
- All sources used or referred to have been documented and recognised.
- This thesis has not previously been submitted in full or partial fulfilment of the requirements for a qualification.
- I am fully aware of Rhodes University's policy on plagiarism and I have taken every precaution to comply with the regulation.
- Ethics clearance number for this research project is **2021-4962-6121**.



Date: **30 November 2022**

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CHAPTER 1:
INTRODUCTION

This chapter provides a background to this research. The reasoning behind conducting this research will be outlined in order to articulate the importance of the findings towards contributing to the body of knowledge related to personal health dashboard design. The goals, method utilized, scope of study and ethical considerations will be detailed in this chapter. Lastly, an outline of chapters will provide an overview of each chapter of this research.

1.1. BACKGROUND

Paper-based healthcare information systems often result in health data that is fragmented and it requires a lot of cognitive effort for interpretation which often leads to a lack of overview; this can significantly increase the rate of medical errors (Swartz et al., 2014). As a result, electronic healthcare information systems were introduced in healthcare facilities to integrate information traditionally found in ‘silos’ (Swartz et al., 2014). Electronic healthcare information systems are increasingly being adopted in the healthcare industry and they are designed for both healthcare providers and patients (Wågbø, 2014). Similarly, South Africa has implemented “The National Digital Health Strategy for South Africa 2019-2024” that aims at improving healthcare for the country through the use of digital technologies that will transform the health system (South African National Department of Health, 2019). However, healthcare digitization (the move from paper-based to electronic healthcare information systems) generally leads to an increase in volumes of health data (Theis, 2019).

Healthcare providers are continually faced with large volumes of health data generated from patients that should be reviewed and processed. This overwhelming task overloads the healthcare providers cognitively and has been further exacerbated by healthcare digitization (Pollack & Pratt, 2020; Meidani et al., 2021). Although, inundating the healthcare provider with large volumes of electronic information can be overwhelming, a study by Daley et al. (2013), showed that healthcare providers would rather not return to using paper-based healthcare information systems. This is because the new way (i.e. electronic way) of accessing a single pool of health data supports effective evidence based decision-making (Rouhani et al., 2018). The healthcare providers’ work environment is complicated and involves switching between a number of tasks and patients while making life or death decisions. Healthcare providers are faced with the challenge of maintaining “situation-awareness” (i.e. knowing all relevant information across distributed systems and understanding what is going on around them). If the healthcare providers experience a challenge with monitoring the patient’s state

continuously; situation-awareness will be lost (Franklin et al., 2017; Theis, 2019). Maintaining situation-awareness requires memory, attention, strategic task management, and access to the right information; the latter is often a difficult task (Franklin et al., 2017). In order to reduce the amount of cognitive effort required to interpret large volumes of health data, clinical dashboards are being developed to present health data stored in these electronic healthcare information systems in an appropriate manner for making informed decisions (Swartz et al., 2014). Clinical dashboards are designed for healthcare providers to present health related data in a usable, concise and visual format; and in a timely and accurate manner for supporting decision-making (Daley et al., 2013). These dashboards have both a visual and functional aspect. The visual aspect deals with presenting information in an easily interpretable manner – through data visualization. Data visualization is regarded as a way to present high volumes of data in a manner that is easily interpretable. In other words, it can be described as the ability to transform or process data, extract value from it, and visualize and communicate it (Chen, 2017a). The functional aspect allows the user to interact with the presented data easily, in order to gain further insights from the health data (Yigitbasioglu & Velcu, 2012).

Dashboards are regarded as a use case of data visualization; as stereotyped by the visualization community. On the contrary, they are a display of visual information that allow users to monitor current conditions quickly and to respond when necessary (i.e. they are much more than just a “subset” of data visualization). Zheng (2017) indicates that a “*Dashboard = Data + Visualization + UI*”. Dashboards encapsulate various aspects of data visualization and offer a better experience for the user by providing features that allow interaction with the data (Sarıkaya et al., 2019). Therefore, dashboards provide a solution to cognitive overload – through data integration and transformation into useful information for interaction, interpretation, and effective decision-making. They effectively transform volumes of original (raw) data into an easily interpretable manner for informing decisions (Abduldaem & Gravell, 2019; Meidani et al., 2021). *Thus, an effective dashboard can be regarded as a one that presents data in an easily interpretable manner; and allows the user to easily interact with data for informed decision-making.*

Traditional health data presentations are usually designed for healthcare providers and are not suitable for ordinary individuals (Soares, 2020). Ordinary individuals can be regarded as the general population (e.g. patients) who are not healthcare providers and have an interest in data about their health. Ordinary individuals use health data for self-awareness, and self-reflection

to make healthcare related decisions (Alrehiely et al., 2018). Ordinary individuals want to view personal health data that healthcare providers use (i.e. their interest in their own health is growing) but they prefer it to be presented in a different manner; the health data is not used in a professional capacity (Zide, 2016; Turchioe et al., 2019). Thus, the desire to provide ordinary individuals with access and control of their health data in an interpretable manner. New technology, such as Internet of Things (IoT), is being put in place to provide ordinary individuals with an opportunity to collect and access their health data easily (Karampela et al., 2018; Jin & Li, 2019). This allows them to take a more active role in being informed and making healthcare related decisions (Visvalingam et al., 2018). In addition, electronic healthcare information systems that are used by healthcare providers are being extended to Personal Health Records (PHRs) in order fulfil this need (Wågbø, 2014; Colley et al., 2016).

A PHR is an electronic application that captures and stores a variety of medical records that are managed and maintained by ordinary individuals or any other individual authorized by the individual; for continuous care (Kyazze et al., 2014; Wågbø, 2014; Zhou et al., 2019; Nazi et al., 2020). A PHR is designed to support caregivers while also encouraging improved self-care and self-management, thus, enabling more control over one's health. Ordinary individuals are given autonomy over taking care of their health, through aggregating, analysing and maintaining their own data for data-driven healthcare decisions (Colley et al., 2016; Theis et al., 2017; Zhou et al., 2019). Ordinary individuals access their PHRs which often include professional medical information and personal health data that is administered by ordinary individuals (e.g. clinical visits summaries, test results, prescriptions, food and liquid consumption, medications, alcohol and caffeine intake, illness-related symptoms, mood and logged exercises) (Theis et al., 2017). Personal health data allows people to gain insights and make data-driven decisions that encourage positive behaviour changes (Alrehiely et al., 2020). Personal health data is provided to individuals at their request; to empower self-care and management (Taha et al., 2013; Colley et al., 2016; Jin & Li, 2019; Turchioe et al., 2019). The process of taking care or managing oneself (including others e.g. family or community) enhances mental, physical, and emotional well-being, without professional/ medical assistance (Godfrey et al., 2011; Buck et al., 2015; Alrehiely et al., 2018). Furthermore, better results - in health outcomes and status - are observed when ordinary individuals are given the opportunity (i.e. empowered) to be actively involved in self-care and self-management - the more the ordinary individuals know, the better" (Andry et al., 2009; Wågbø, 2014).

However, individuals are challenged with extracting insights from personal health data. These challenges revolve around: 1) information overload (i.e. large volumes of personal health data), and 2) the difficulty of understanding the personal health data easily; leading to individuals' anxiety and stress (Alrehiely et al., 2018; Jin & Li, 2019; Nazi et al., 2020). Personal health data is generated in large volumes and has to be converted in a manner that can be easily understood. Therefore, an optimal way of presenting the data must be determined and used (Alrehiely et al., 2018; Giordanengo et al., 2019). Furthermore, personal health data is filled with medical jargon (i.e. language/ terms only understood by healthcare providers) that is often unfamiliar to ordinary individuals and values that often increase the complexity of the data (Taha et al., 2013; Turchioe et al., 2019). This may result in confusion and subsequent misinterpretation of personal health data (Visvalingam et al., 2018). Thus, there is a need for ensuring that personal health data is easily comprehensible to a wide range of individuals (i.e. beyond healthcare providers) (Zide, 2016). Complexity coupled with the increasing volumes of generated personal health data – due to the electronic age/ healthcare digitization – makes it difficult for individuals to contextualise and interpret their personal health data (Jin & Li, 2019; Turchioe et al., 2019). Most personal health data information systems provide representations of data; however, they do not often meet the user's data presentation needs (Alrehiely et al., 2018). Therefore, there is a need for research on better ways for presenting personal health data in order to address these issues (Nazi et al., 2020). Better ways (e.g. user-friendly and accommodating presentation) of presenting health data to individuals can significantly assist them in understanding their health data, thus, allowing them to make informed decisions (i.e. for self-care and management) (Visvalingam et al., 2018; Koopman et al., 2020; Soares, 2020). Research shows that ordinary individuals need specific and summarized personal health data that minimizes the cognitive effort required to interpret the data (Prioleau et al., 2020).

Solutions that allow users to understand or reflect on their personal health data will improve the benefits of accessing this data (Prioleau et al., 2020). Similar to what has been done for healthcare providers, the visualization community is making efforts towards understanding how to better help people collect and analyse data for personal insights (Lee et al., 2020). Dashboards have the potential to put individuals in a better position to discover or recognise anticipated and unanticipated patterns from personal health data. Thus, timely and comprehensible evaluation of oneself allows timely decisions to be made (e.g. take medication and/ or visit a doctor). However, the dashboard has to provide quality information to ensure high quality decisions (Rouhani et al., 2018).

Various authors have attempted to presenting personal health data to ordinary individuals. Jin & Li (2019) focused on designing visualizations for presenting data captured by wearable devices in an easily interpretable manner and recommended four functions (i.e. overview, temporal and horizontal comparison, and detailed annotation) of a visualization system. Similarly, Zide (2016) focused on developing a protocol for designing visualizations that provide information to patients; and gave insights on “themes that can be used as the basis for guidelines for patient portal development”. On the other hand, Visvalingam et al. (2018) focused on comparing health related applications and indicated that there is a need for “a general guideline to aid the development of self-reflective visuals”. However, there is still limited literature and empirical evidence on the design of personal health related dashboards (Meidani et al., 2021). There is no homogeneous (i.e. “one-size-fits-all”) approach to meeting all personal health data presentation needs because ordinary individuals are different in terms of attributes such as cultural context, health literacy, and cognitive status - all of which affect the way they interpret personal health data (Zide, 2016; Turchioe et al., 2019). However, designers of health related tools should strive to meet the various health data presentation needs. Based on the paucity of information related to the design of personal health dashboards, this research aims at developing a set of design guidelines that can form the foundation of personal health dashboard designs and make a better contribution than merely designing a “perfect” dashboard that caters for specific user needs. Design guidelines are a summary of “good design practices” (Miniukovich et al., 2017) that provide general instructions on how to design a dashboard. They have the potential to bring the initial version of a dashboard closer to an ideal final version, contrary to if the guidelines had not been utilized at all (Gould & Lewis, 1985).

1.2. PROBLEM STATEMENT

Healthcare providers use health data for the purposes of taking care of ordinary individuals. The healthcare industry has realised the benefits of providing personal health data to ordinary individuals through PHRs and IoT devices. Providing ordinary individuals with personal health data encourages self-care and self-management. However, the personal health data is stored in large volumes and it is often complex – thus making it difficult to easily interpret. Researchers have mainly focused on presenting health data for healthcare providers; however, there is limited focus on presenting health data for ordinary individuals. These ordinary individuals

require tools that can present personal health data effectively. Dashboards provide a solution for these personal health data presentation needs. However, individuals are different; thus, a homogeneous (i.e. “one-size-fits-all”) dashboard design is, arguably, impractical. Therefore, design guidelines that can form the basis for tailoring dashboards for different personal health data presentation needs can help accommodate a vast array of individuals who want to understand personal health data.

1.3. RESEARCH OBJECTIVES

The aim of this research is to create design guidelines for the development of personal health dashboards and to determine the quality of these guidelines.

1.4. RESEARCH QUESTIONS

In order to fulfil this objective, the following research questions are presented:

RQ1: What design aspects should be incorporated into the design guidelines for personal health dashboards?

This research question identifies the visual design aspects that can be used to present personal health data effectively; and identifies the functional design aspects that allow the user to be able to easily interact with and understand the presented data. This allows a set of design guidelines to be synthesized based on the insights discovered.

RQ2: How successful are the guidelines at designing an effective personal health dashboard?

This research question looks at evaluating the efficacy and utility of the design guidelines in creating a dashboard that presents personal health data effectively. This ensures that the guidelines are of good quality.

1.5. RESEARCH METHODOLOGY

This research follows a pragmatism research philosophy. Pragmatism aims at balancing objectivism and subjectivism. It ensures contributions of practical solutions to a stated problem; these solutions can be used to inform or guide future practice. Pragmatism focuses on practical outcomes instead of (i.e. more than) abstract distinctions (Saunders, 2016). Design Science Research (DSR) is well suited in pragmatism as it is a problem-solving approach (Hevner et al., 2004; Vaishnavi et al., 2019), which aims to produce design artifacts that may be used to contribute towards research and provide solutions to real-world problems. This approach is now well established within the Information Systems discipline (Gregor & Hevner, 2013a). In order to fulfil the Design Science Research requirements, the Design Science Research Process model (Figure 1.1) of Peffers et al. (2008) will be used to guide the research.

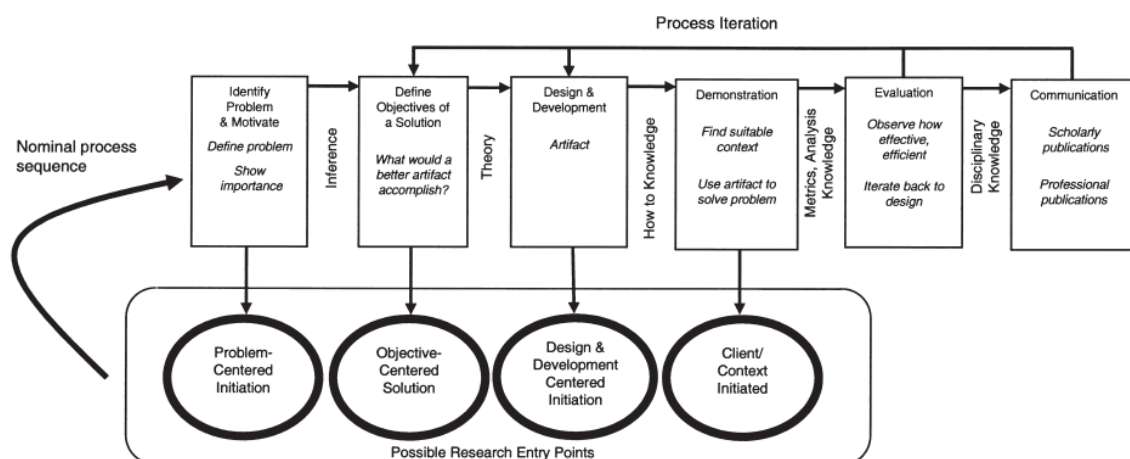


Figure 1.1 – Design science process model (Peffers et al., 2008)

For this research, the six activities identified for the DSRP (Peffers et al., 2008) are undertaken as follows:

- Problem identification and motivation:** *In this activity, a research problem is defined, and the value of its solution is justified.* A literature review will be conducted to understand the issues faced by individuals who want to see an overview of their personal health data (Chapter 1).

- **Define the solution objectives:** *This activity focuses on quantitative (e.g., better functionality/ performance) or qualitative (e.g., how it will solve problems) objectives based on known possibilities and feasibility from the problem definition. A literature review will assist in discovering what has been done in visualization and dashboards (i.e. both in general and in healthcare) to gain insight into design aspects (features) that are relevant to this study (Chapter 3, 4, 5, 6).*
- **Design and Development:** *In this activity, the artifact is designed and created (including its functionality and architecture). The dashboard design categories of Jespersen (2017) will be used to structure the set of design guidelines based on design aspects (features) learned from the literature (Chapter 3, 4, 5) and focus groups (Chapter 6)*
- **Demonstration:** *During this activity, the artifact is used to show (demonstrate) how it solves a problem or part of it. The proposed design guidelines (Chapter 7) will be used to develop a medium fidelity dashboard prototype that will be evaluated by participants.*
- **Evaluation:** *In this activity, the artifact is evaluated to see to what extent it solves the problem. The guidelines are evaluated for efficacy, utility and quality through usability testing (Chapter 8) of the dashboard prototype.*
- **Communication:** *In this activity, the problem and its value, the artifact's utility, novelty and the rigor of the design, and its effectiveness to the researchers and relevant stakeholders are communicated. The theoretical and practical contribution of this research to the body of knowledge will be communicated in the final thesis and via journal/conference contributions.*

1.6. SCOPE OF STUDY

This research focuses on developing a set of dashboard design guidelines for presenting personal health data. Hence, the scope of this research is limited to visual and functional design aspects for presenting personal health data effectively. This research only focuses on uncovering good design aspects that can form the “front-end” foundational design of personal health dashboards. “Back-end” design aspects such as, data repository connections, performance and security do not form part of the research scope.

1.7. ETHICAL CONSIDERATIONS

Ethics approval was acquired from the Rhodes University Human Ethics Committee because human subjects were recruited to take part in this research. The ethics tracking number provided is - 2021-4962-6121. All participants took part in this research on a voluntary basis; informed consent (Appendix A.) was required before participation. All ethical considerations around anonymity, confidentiality, and non-disclosure were strictly adhered to.

1.8. OUTLINE OF CHAPTERS

This thesis is structured as follows:

CHAPTER 1: INTRODUCTION

This chapter provides a background to this research. It introduces the main idea of this research. The research objectives, goals, methodology and scope are outlined.

CHAPTER 2: RESEARCH METHODOLOGY

The research methodology (Design Science Research approach) is detailed including how it is utilized to develop the set dashboard design guidelines.

CHAPTER 3: DATA VISUALIZATION

This chapter presents details on visualization and on its importance concerning presentation of information in graphical format. The chapter includes Tufte’s principles, information communication, visual perception, cognitive-fit theory, cognitive framework, and individual factors.

CHAPTER 4: DASHBOARDS

This chapter details design aspects of dashboards in general. All related aspects about dashboard designs are discovered. Furthermore, this chapter forms the foundation (i.e. structure) of the set of dashboard design guidelines. This chapter includes visual and functional features and preliminary design aspects.

CHAPTER 5: HEALTH DASHBOARDS

This chapter focuses on health dashboards. The chapter provides information about dashboards used in the professional healthcare space (clinical) and ones used by general users (i.e. patients/ordinary people) for viewing personal health data. Design aspects relevant in the healthcare domain are identified to inform the dashboard design guidelines.

CHAPTER 6: FOCUS GROUPS

This chapter aims at understanding the degree to which the insights gained from the previous chapters (i.e. visualization and dashboards) are in alignment with what ordinary individuals would want and or need from a health dashboard. Thus, improving the design aspects that were learned or understood from the Chapters 3, 4 & 5.

CHAPTER 7: PROPOSED DESIGN GUIDELINES

This chapter presents a set of proposed dashboard design guidelines that are based on all the learnings (i.e. insights) from the literature review and the focus groups. The set of guidelines are the foundation of the dashboard prototype that is used to test their efficacy and utility at presenting personal health data in easily interpretable information.

CHAPTER 8: GUIDELINE EVALUATION

This chapter provides details on the evaluation of the dashboard prototype that was designed based on the set of proposed design guidelines. The dashboard prototype provides insights on the efficacy and utility of the proposed design guidelines for developing a dashboard that presents personal health data effectively; thus, improving the quality of the design guidelines

CHAPTER 9: CONCLUSION

This chapter provides a conclusion of all findings (i.e. final set of dashboard design guidelines) and details on the successes and limitations of this research. Also, it looks at areas that need to be explored or investigated further in the near future.

CHAPTER 2: RESEARCH METHODOLOGY

Research in the field of visualization results in the development of a certain purposeful artifact that visually presents information. Similarly, design science research aims at constructing an artifact; therefore, it can be argued that design science research is an approach that is appropriate for research on how to visually present data effectively (Engelbrecht et al., 2015). This chapter aims at justifying and outlining design science research and discusses the value of utilizing it to develop guidelines for designing dashboards that present data holistically and effectively. The decision to use this approach is based on the success seen in studies that have used design science to develop dashboards (Martin et al., 2018; Pestana et al., 2020).

2.1. OVERVIEW

Design science is a problem-solving paradigm and it is underpinned by sciences of the artificial, and engineering (Hevner et al., 2004; Hevner & Chatterjee, 2010). Design can be described as “to invent and bring into being” (i.e. creating new or innovative artifacts); on the other hand, research is an activity that is undertaken to understand a phenomenon. Design science research is a field that continues to evolve rapidly – the name “design research” was recently changed (i.e. within the last decade or so) to design science research. Information Systems researcher decided to add the word “science” to distinguish “using design as a research method” or technique from “research about design” (Vaishnavi et al., 2019). Since the 1990s, the IS community has given recognition to design science research for improving the utility and effectiveness of IT artifacts in order to solve real-world (organizational) problems. Design science research looks at two primary activities for improving and understanding the behaviour of Information Systems aspects (Vaishnavi et al., 2019): 1) innovative or novel artifacts are designed to create new knowledge; 2) reflection and abstract analysis of the performance and/or use of the artifact. Due to the emphasis on the relevance of the design artifact, design science falls under the pragmatic philosophy.

2.2. RESEARCH PARADIGM

A paradigm is a system of thinking and provides the framework or model for observation and understanding (i.e. it guides action). It includes accepted approaches, traditions, theories, frame of reference, models, body of research and methodologies (Vosloo, 2014).

POSITIVISM

Positivism paradigm fall under an objective epistemology (Figure 2.1) and applies natural science methods to a quantitative research. “A phenomena must be measured and supported by evidence” (Pham, 2018). This is usually done through experiments that ensure that relationships between an independent and dependent variable to be identified (discovered). This paradigm “entails a belief that valid knowledge can only be produced on the basis of direct observation by the senses; and this would include the ability to measure and record that would be seen as knowledge” (Vosloo, 2014). The researcher is independent - detached, neutral, in a non-interactive position, and distant – of the research (findings). The results of a positivism research are generalizable, however, at the expense of neglecting to understand and interpret individuals who are affected by events, issues, or phenomena being studied (Pham, 2018). Empirical evidence is prioritized and does not leave room for phenomena (evidence) that cannot be directly observed such as attitudes and thoughts. Scientific theories are “hypothesised” and empirically tested (thorough examination) to allow conclusions to be made (i.e. acceptance or rejection of the hypothesis). This paradigm is inclined towards using quantitative methods for data collection and analysis (Vosloo, 2014).

INTERPRETIVISM

Interpretivism paradigm takes a subjective view (Figure 2.1) and allows a deeper understanding to be gained from the phenomenon, its complexity and specific context without the need for generalizing the understandings (Pham, 2018). It attempts to understand people and uncovers meaningful explanations. It acknowledges that humans try to make sense of the world they live in through interpreting, giving meaning, creating, defining, rationalising, and justifying daily actions. Interpretivism research allows interpretation and understanding everyday events, social structures and values, and experiences. An interpretivism research is driven by “interests” and the researcher is immersed (part of) in what is being observed. Interpretivists aim to understand the observations and experiences of the world within different contexts and

culture without adding bias of their own interpretations to the study. “*The researcher is required to dig into the processes of subjective interpretation, acknowledging the motivations, interests, intentions, beliefs, values and reasons, meaning-making and the self-understanding of the participants*” (Vosloo, 2014). This approach is inclined towards the use of qualitative methods of data collection and analysis.

PRAGMATISM

“Pragmatism is a school of thought that considers practical consequences or real effects to be vital components of both meaning and truth” (Hevner, 2007). Design science aims at solving real-world problems through creative and innovative artifacts. In other words, design science allows an IT artifact, relevant to the application domain, to be created (Hevner & Chatterjee, 2010). The design science researcher is regarded as a pragmatist (Vaishnavi et al., 2019). Thus, this research will be based on the pragmatism research philosophy. Pragmatism aims at balancing objectivism and subjectivism (i.e. positivism and interpretivism). It ensures contributions of practical solutions on a stated problem; these solutions can be used to inform or guide future practice. Pragmatism focuses on practical outcomes instead of (more than) abstract distinctions (Saunders et al., 2016).

Basic Belief	Research Perspective		
	Positivist	Interpretive	Design
Ontology	A single reality; knowable, probabilistic	Multiple realities, socially constructed	Multiple, contextually situated alternative world-states. Socio-technologically enabled
Epistemology	Objective; dispassionate. Detached observer of truth	Subjective, i.e. values and knowledge emerge from the researcher-participant interaction.	<i>Knowing through making</i> : objectively constrained construction within a context. <u>Iterative circumscription</u> reveals meaning.
Methodology	Observation; quantitative, statistical	Participation; qualitative. Hermeneutical, dialectical.	Developmental. Measure artifactual impacts on the composite system.
Axiology	Truth: universal and beautiful; prediction	Understanding: situated and description	Control; creation; progress (i.e. improvement); understanding

Figure 2.1 – Philosophical assumptions of positivist, interpretive and design science research perspectives (Vaishnavi et al., 2019).

2.3. DESIGN SCIENCE RESEARCH

In design science, an artifact is built and applied to gather knowledge and understand the problem domain (Hevner et al., 2004). DS allows IT artifacts to be rigorously created and evaluated (i.e. utility, efficacy, and quality) for heretofore-unsolved organizational problems. This is done through using existing knowledge and theories to create solutions to defined problems. The design and proof of its value are the most important aspects of DS research (Peppers et al., 2008). Design science can be broken down into two parts: *a set of activities (process)* that produces a new product, and an *artifact (product)* that provides feedback data through evaluation in order to make improvements once the problem is fully understood. Therefore, this is an iterative method that leads to building and evaluating until a final design is accepted (Hevner et al., 2004). In other words, a build-and-evaluate loop (iteration) underpins the design process of the artifact in order to make improvements (i.e. on the quality) of the final design (Hevner et al., 2004).

In the IS field, design science research aims to address the business needs through building and evaluating artifacts (i.e. utility) (Hevner et al., 2004). It allows researchers to turn “human” creativity into artifacts designed and built to be used or applied in certain environments. Design science is different from routine design by addressing “wicked problems”. “Wicked problems” need novel, creative and innovative solutions e.g. through paradigm shifts which are more effective and are the results of design science research (Hevner & Chatterjee, 2010). Design science research addresses crucial unresolved problems in innovative and/or unique ways, or solved problems with improved, efficient and effective ways. The results of design science are then codified into the knowledge base, thus becoming “best practices” that can be used for professional design (Hevner & Chatterjee, 2010). The aim is to solve a “wicked” problem through designing an artifact that supports the process of extracting valuable and intuitive information from complex data in order to simplify the data and inform decision-making.

The design science research (project) contributes to knowledge in many valuable and innovative ways; design theories (natural science activity) and artifacts – constructs, frameworks, models, design principles, architectures, methods, and/or instantiations (Vaishnavi et al., 2019). Outputs of design science research are summarized in Figure 2.2.

	Output	Description
1	Constructs	The conceptual vocabulary of a domain
2	Models	Sets of propositions or statements expressing relationships between constructs
3	Frameworks	Real or conceptual guides to serve as support or guide
4	Architectures	High level structures of systems
5	Design Principles	Core principles and concepts to guide design
6	Methods	Sets of steps used to perform tasks—how-to knowledge
7	Instantiations	Situated Implementations in certain environments that do or do not operationalize constructs, models, methods, and other abstract artifacts; in the latter case such knowledge remains tacit.
8	Design Theories	A prescriptive set of statements on how to do something to achieve a certain objective. A theory usually includes other abstract artifacts such as constructs, models, frameworks, architectures, design principles, and methods.

Figure 2.2 – Design science research contributions or outputs (Vaishnavi et al., 2019)

The four general outputs are constructs, models, methods, and instantiations (March & Smith, 1995; Hevner et al., 2004; Vaishnavi et al., 2019).

- **Constructs** (symbols and vocabulary) are the language used to define and communicate the problem and its solution. They are derived when the problem is conceptualized and refined during the research cycle.
- **Models** (representations and abstractions) turn constructs into a real world situation to show how the components of problems and solutions are linked, and how the changes in design affects the environment. They are problem and solution propositions or statements that details on “how things should be done”.
- **Methods** (guidelines, practices and algorithms) are processes that guide designers in solving problems. They provide plans that aim at realizing solution statement models through construct manipulation.
- **Instantiations** (Implementations) realizes the “material” artifact in its application environment through implementing constructs, models and methods into a working product (system). Thus, they “demonstrate” the effectiveness, usefulness, feasibility, and/or suitability of the artifact (i.e. for its intended purpose).

The knowledge that is contributed by design science research can fall into one of the four quadrants of the knowledge contribution framework (Figure 2.3). **Invention** – new solutions/ knowledge for new problems; **Improvement** - new solutions/ knowledge for known problems; **Adaptation (expansion)** - novel, innovative or non-trivial adaption or extension of know solutions/ knowledge for new problems; and **Routine design** – applying known solutions/ knowledge for known problems (Gregor & Hevner, 2013b; Vaishnavi et al., 2019). This

research will be inclined towards the **Adaptation** quadrant of the framework due to the design of an artifact (design guidelines) based on “adapted” known solutions for discovered problems that are related to presenting personal health data effectively.

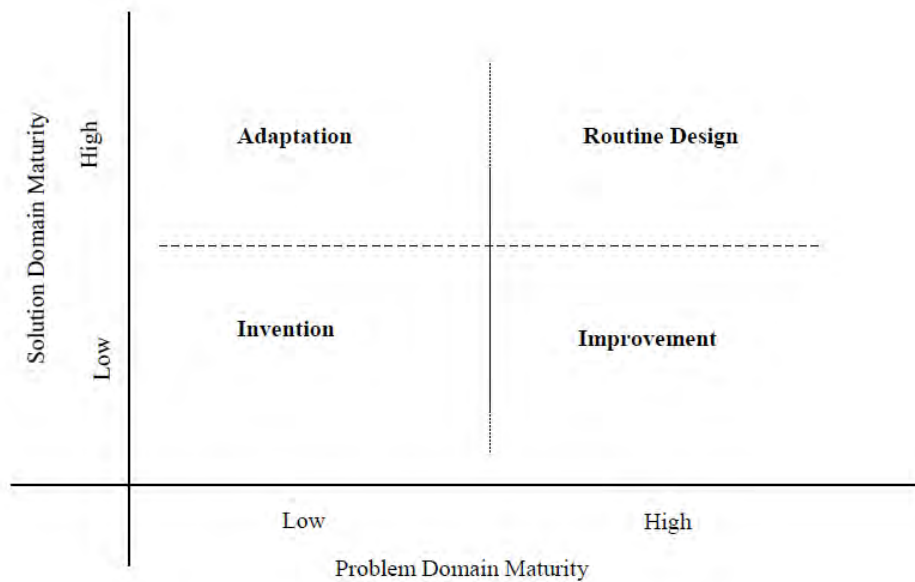


Figure 2.3 – Knowledge contribution framework (Vaishnavi et al., 2019)

2.4. DESIGN SCIENCE RESEARCH CYCLE

Design science is differentiated from other research paradigms through the recognition of three cycles that a research project undergoes (Hevner, 2007). Design science research follows cycles of relevance, rigor and design (Figure 2.4).

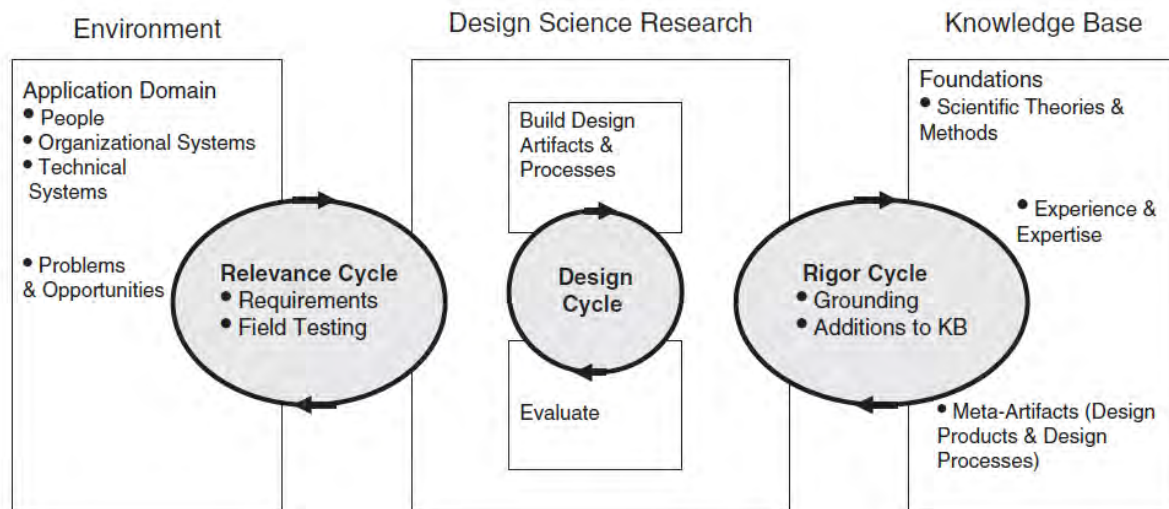


Figure 2.4 – Design science research cycle (Hevner & Chatterjee, 2010)

2.4.1. Relevance Cycle

This cycle focuses on making improvements in the environment (application domain) through introducing innovative and novel artifacts (and processes for building such artifacts). The application domain or environment consists of interaction – towards a common goal – between technical systems, people and the organization (Hevner, 2007). This cycle ensures that the design science research is conducted with the requirements and acceptance criteria (i.e. for evaluation) of the application context, in mind (Hevner & Chatterjee, 2010). The outputs of the design science research should be studied and evaluated in the application domain (Hevner, 2007).

The problems related to graphically presenting personal health data will be understood and a solution (in a form of design guidelines) will be aligned with the application domain.

2.4.2. Rigor Cycle

This cycle emphasises the need to “stand on the shoulders of giants” in order to apply past knowledge into the research project; the research should thoroughly find and reference the knowledge base that will ensure that the project produces artifacts for making valuable, innovative and novel contributions. Thus, routine design that applies known design processes and produces known design artifacts is avoided. Skilled selection and application of relevant (existing) theories and methods is important for creating and evaluating the artifact (Hevner & Chatterjee, 2010). Results of the design science research are added to the knowledge base e.g.

new extensions to methods and theories, meta-artifacts (design processes and products), and all experiences acquired through the research process (Hevner, 2007).

Literature review conducted allows enough knowledge to be gained in order to inform the findings of this research and the output is a set of design guidelines that are added to the “knowledge base”.

2.4.3. Design Cycle

The previous mentioned cycles (relevance and rigor) provide inputs such as requirements, theories and methods for this cycle. Relevance and rigor activities should be applied in the construction and evaluation of the design artifact (Hevner & Chatterjee, 2010). Therefore, this cycle forms the heart of the design science research through the construction and evaluation phases of an artifact; subsequent feedback iterates the design process for refining the artifact until a level of satisfaction is achieved (Hevner & Chatterjee, 2010). A balance should be stricken between construction and evaluation efforts throughout the evolution of the artifact (Hevner, 2007). The created artifact needs to be evaluated to ensure it solves a problem (or part of it). Evaluation is what puts the ‘Science’ in ‘Design Science’” (Venable et al., 2012).

Relevant theories and stakeholders (i.e. users of the designed prototype) inform the design of the artifact of this research. Feedback gained from stakeholders allows the refinement of the designed prototype thus informing the final set of appropriate guidelines.

2.5. DESIGN SCIENCE RESEARCH GUIDELINES

Design science aims to develop things that can “serve human purposes” (Peppers et al., 2008). There are seven guidelines that ensure a known design problem is understood and the solution is derived from building and applying (evaluation) an artifact (Hevner et al., 2004).

- **Guideline 1:** Design as an artifact

Design science should produce innovative and purposeful artifacts (i.e. in a form of constructs, methods, models, and or instantiations).

A set of guidelines for designing dashboards that present personal health data effectively are developed.

- **Guideline 2: Problem Relevance**

A problem is defined as the gap between the current state and ideal state of the system. An artifact is designed or created for a specific problem domain i.e. to solve “important business problems”.

A well-designed dashboard has the potential to solve a number of problems (i.e. large volumes of complex personal health data) experienced by individuals who want to view their personal health data in an easily interpretable manner. The guidelines related to designing personal health data dashboards are scarce. Therefore, the design guidelines produced by this research aim at providing a foundation for tailoring dashboards that can present personal health data effectively; also informing decisions.

- **Guideline 3: Design Evaluation**

The artifact must be evaluated to ensure its efficacy, quality and utility. The evaluation phase provides feedback to the iterative design of an artifact until it satisfies the requirements (i.e. addresses the problem).

The demonstration of the set of guidelines through a dashboard prototype allows the evaluation and refinement of the guidelines in terms of their quality (i.e. efficacy and utility). The insights gained from the dashboard prototype evaluation (i.e. through a naturalistic evaluation) will improve and increase the quality of the final set of design guidelines.

- **Guideline 4: Research Contributions**

The artifact should provide novelty in terms of addressing known problems in a more efficient and effective way or should address heretofore-unsolved problems.

The proposed set of guidelines will inform the design of dashboards for presenting an overview of personal health data in order to address challenges related to individuals who want to understand their personal health data and make informed decisions. Thus,

the final artifact of this research will add to the body of knowledge (i.e. adaptation quadrant of the knowledge framework – Section 2.3.)

- **Guideline 5: Research Rigor**

This relates to the manner in which the research is performed (conducted); rigorous methods should be used for constructing and evaluating the artifact.

Literature review related to healthcare and other fields that have used dashboards, and related theories are studied to inform the set of guidelines. Interactions (i.e. through focus groups and usability testing) with the potential dashboard users inform the designing and refinement of the artifact, thus, providing further rigour.

- **Guideline 6: Design as a Search Process**

A problem space is determined and mechanisms are used to provide an effective solution. In other words, a solution is discovered for a problem through understanding the problem (e.g. requirements, constraints) and solution domain.

Analysing literature and insights gained from focus groups (Chapter 1, 3, 4, 5, & 6) provides value to the research through answers discovered for addressing the research questions.

- **Guideline 7: Communication of Research**

The results of the whole research must be presented/ communicated to the appropriate audience to inform future practice.

The final (refined) set of guidelines are presented in the final thesis to inform future practices; and to be communicated to relevant stakeholders.

2.6. DESIGN SCIENCE RESEARCH PROCESS

The design science research process model developed by Peffers et al. (2008) has been chosen to guide this research (Figure 2.5). This model was suitable for this research because it was developed for information systems research and it was built based on the synthesis of other design science process models (Hevner, 2007).

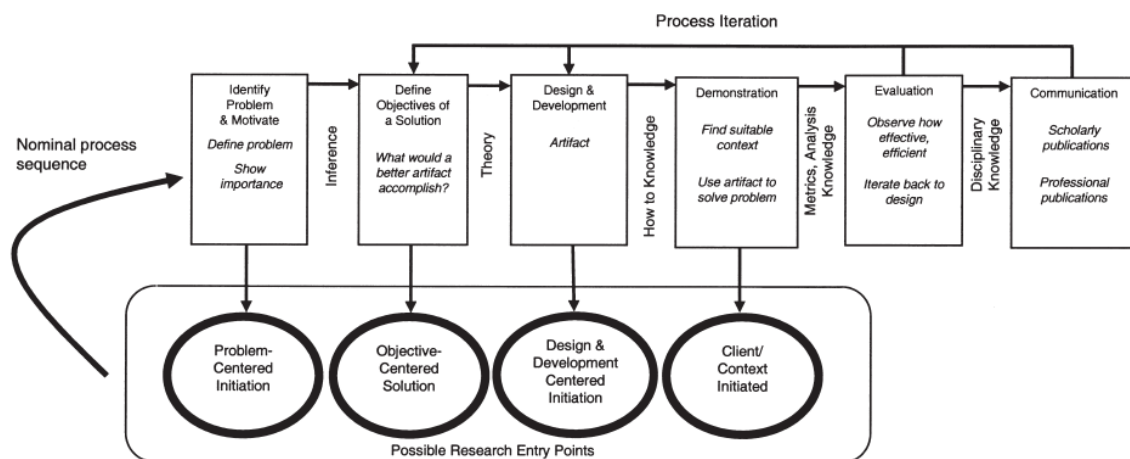


Figure 2.5 – Design science process model (Peffers et al., 2008)

There are six activities identified for DS research (Peffers et al., 2008):

- **Problem identification and motivation:** a research problem is defined and the value of its solution is justified. The problem is defined by breaking it down in order to capture its complexity in the artifact and motivation provides justification to the researcher and the user of the value of the solution.
- **Define the solution objectives:** identify quantitative (e.g. better functionality/performance) or qualitative (e.g. how it will solve problems) objectives based on known possibilities and feasibility from the problem definition.
- **Design and Development:** This is where the artifact is created (including its functionality and architecture) and may be in a form of constructs, models, methods, or instantiations etc. The artifact may be anything that has research contribution embedded into its design.
- **Demonstration:** The artifact is used to show (demonstrate) how it solves a problem or part of it through activities such as experiments, case studies, simulation etc.

- Evaluation:** The artifact is evaluated to see to what extent does it solve the problem. The results of the solution or artifact are weighed against the objectives. The evaluation could be empirical evidence based or logical proof. Researchers can then decide whether to go to the next step, improve the artifact (design and development), or leave it for other projects. Venable et al. (2012) present a framework (Table 2.1) that can be followed to evaluate artifacts. There are two dimensions: naturalistic vs artificial evaluation and ex ante vs ex post evaluation. The evaluation of the artifact of this research is based on the ex post – naturalistic evaluation quadrant (i.e. survey and participant observation) in order to evaluate the demonstrated prototype for deriving the set of guidelines.

Table 2.1 - Design science research evaluation framework (Venable et al., 2012)

DSR Evaluation Method Selection Framework	Ex Ante	Ex Post
Naturalistic	<ul style="list-style-type: none"> Action Research Focus Group 	<ul style="list-style-type: none"> Action Research Case Study Focus Group Participant Observation Ethnography Phenomenology Survey (qualitative or quantitative)
Artificial	<ul style="list-style-type: none"> Mathematical or Logical Proof Criteria-Based Evaluation Lab Experiment Computer Simulation 	<ul style="list-style-type: none"> Mathematical or Logical Proof Lab Experiment Role Playing Simulation Computer Simulation Field Experiment

Ex post evaluation deals with an instantiated artifact (e.g. dashboard prototype) and ex ante evaluation is a predictive evaluation (before design or construction) of the estimated impact of an artifact that is not instantiated (e.g. model). Evaluations methods can also be classified as artificial or naturalistic; the methods can be mixed to combine their strengths. Artificial evaluation can be either empirical or non-empirical evaluation of an artifact in an unreal setting, with unreal users and systems (Venable et al., 2016). It includes mathematical proofs, simulations, laboratory experiments, theoretical arguments and criteria-based analysis. Naturalistic evaluation assesses the extent to which the artifact solves the problems in a real-world environment (i.e. addresses the complexities of real people, systems and settings; this is the goal of this research. Naturalistic evaluation methods include action research, field studies, phenomenology, surveys, ethnography, case studies, and hermeneutic methods (Venable et al., 2012).

- **Communication:** the problem and its value, the artifact's utility, novelty and the rigor of the design, and its effectiveness to the researchers and relevant stakeholders are communicated.

From Peffers et al.'s (2008) model a diagram was created (Figure 2.6) to provide a holistic view of how this research was conducted. Each research activity is elaborated in Table 2.2.

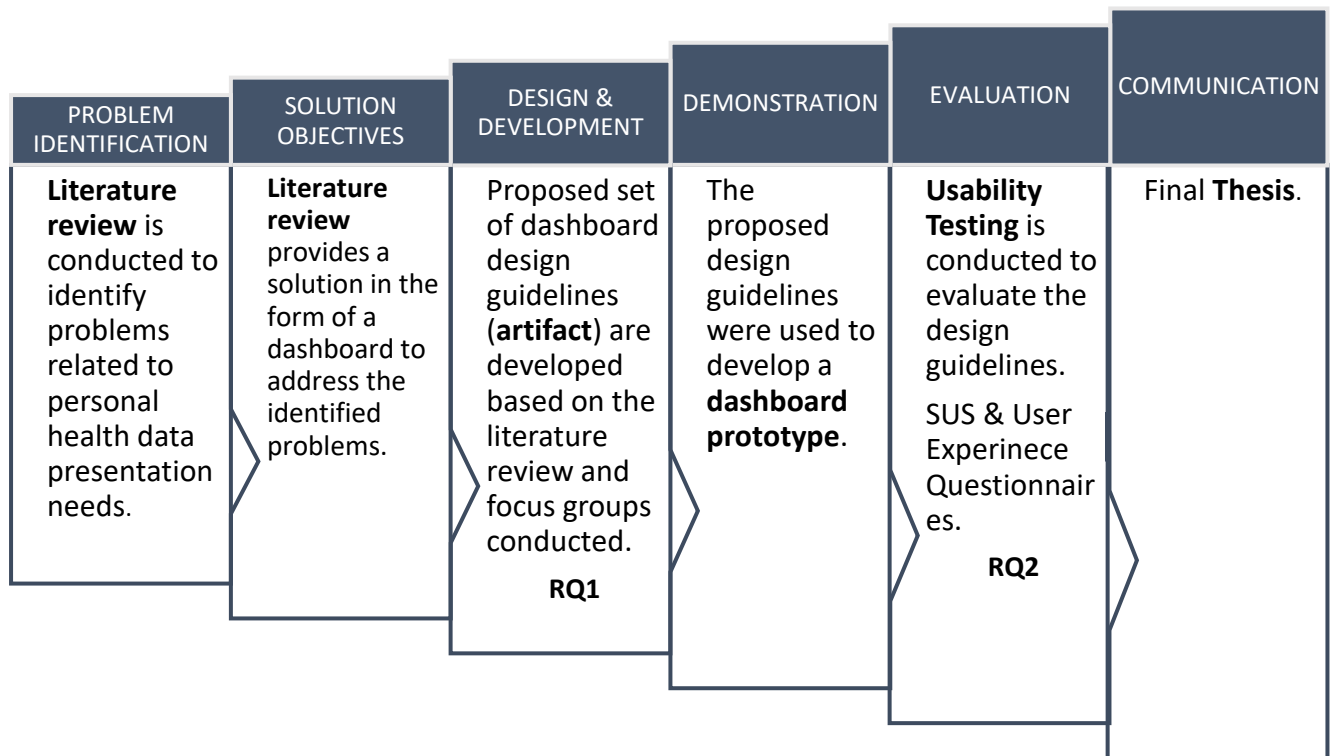


Figure 2.6 – How the research was conducted

Table 2.2 – Elaborated design science research process activities

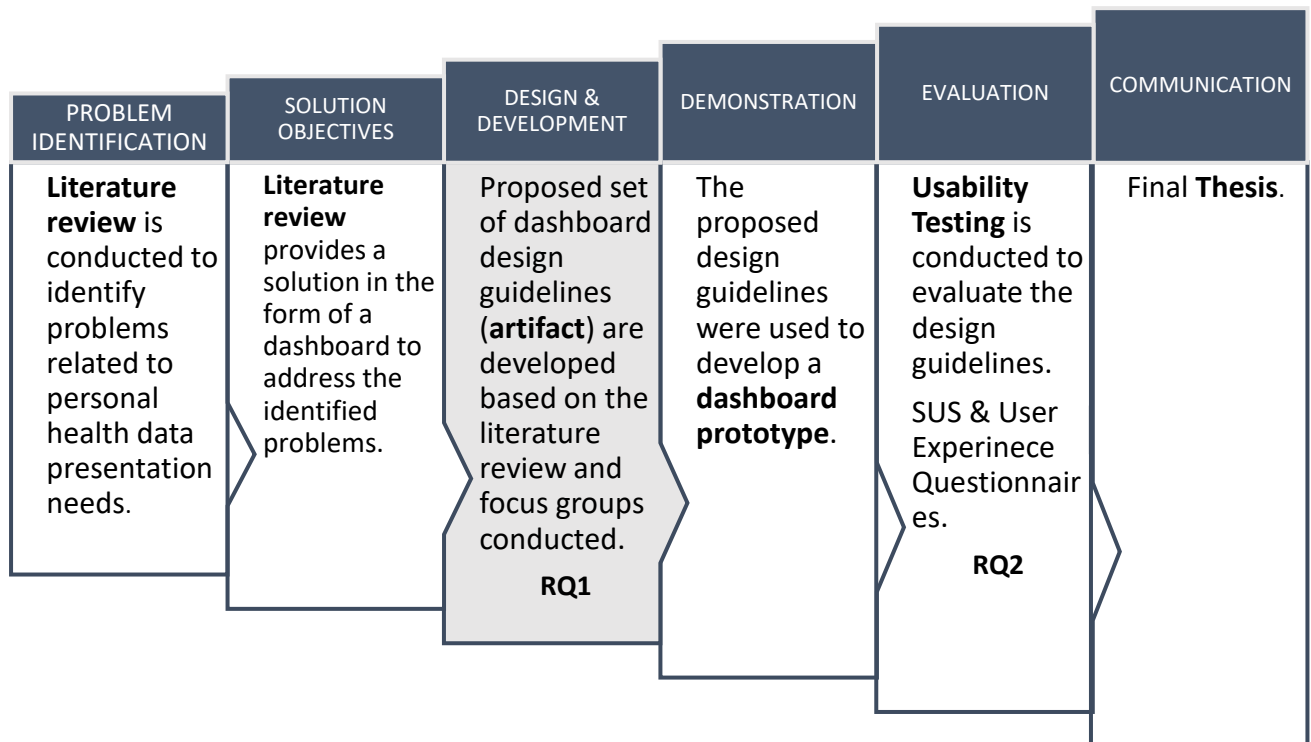
Activity	Application
Activity 1: Problem identification and motivation	Literature review is conducted on issues related to interpreting large volumes of complex personal health data in an easily interpretable manner (Chapter 1)
Activity 2: Define the solution objectives	The literature review provides solutions in the form of dashboards that can be used to present personal health data effectively. The dashboards are regarded as a means of communicating personal health data in a manner that does not require a lot of cognitive effort; thus, supporting self-care and self-management related decisions.
Activity 3: Design and Development	This research aims at developing guidelines that inform the design of personal health data dashboards that support users who want to monitor and/ or understand their health. The development of these

	<p>guidelines will be informed mainly by everything that was learned and understood from the literature (Chapter 3, 4 & 5) and focus groups (Chapter 6). <i>RQ1: What design aspects should be incorporated into the design guidelines for personal health dashboards – is addressed in this activity.</i></p>
<p>Activity 4: Demonstration</p>	<p>An instantiation in the form of a medium-fidelity dashboard prototype will be used to demonstrate the feasibility/ practicality (i.e. utility and efficacy) of the guidelines to the stakeholders (i.e. prospective dashboard users). This dashboard prototype will present the guidelines (i.e. the focal output) in a “visual” form, in a practical setting.</p>
<p>Activity 5: Evaluation</p>	<p>Usability testing (Chapter 8) on the dashboard prototype will allow the design artifact (design guidelines) to be evaluated. In addition, System Usability Scale and User Experience questionnaires are used to further evaluate the instantiation (dashboard prototype) thus allowing for improvements to be made on the quality of the artifact (design guidelines). <i>RQ2: How successful are the guidelines at designing an effective personal health dashboard? – is addressed in this activity.</i></p>
<p>Activity 6: Communication</p>	<p>The final set of guidelines will be communicated in the final thesis to inform future practices</p>

2.7. CONCLUSION

This chapter detailed on design science research, the rationale for conducting and how the approach was applied by this research. This approach was chosen because it aims at addressing a real world problem by developing a design artefact that offers a suitable solution; this research aims at creating a set of guidelines that can be used to solve problems relating to presenting personal health data in an easily interpretable manner. To ensure that the guidelines are valuable (domain specific) and feasible (practical), this approach (design science research) provides a six step systematic (formal) way of development and evaluation of an artifact (Peffer et al., 2008).

CHAPTER 3:
DATA VISUALIZATION



This chapter provides details on data visualization and its value to this research in terms of how it can allow personal health data to be presented in a manner that is easily interpretable and can inform the users' health-based decisions. This chapter discusses the most essential part of the dashboard that communicates/ presents raw data into a more interpretable format. This chapter will also dive into related theories such as Tufte's guidelines, information communication, cognitive fit, visual perception, dual-process cognitive framework, and individual factors, to provide an understanding of how individuals assimilate information that is graphically presented.

3.1. OVERVIEW

Data visualization can be traced back to the 16th century (Chen, 2017a). During this period, geometric maps and diagrams aided and were utilized for exploration and navigation. Since then, visualization has drastically changed through methodologies introduced within each century (Chen, 2017a). Furthermore, the proliferation of computers since the 1980s has led to large, complex data volumes due to the continued rapid adoption of information technology (computers) used (Ko & Chang, 2017). For this data to be understood and analysed, it needs to be appropriately transformed into visual representation (Chen et al., 2015).

The result of visualization should be insight. Data, information and knowledge are terms that are commonly used in visualization and represent different levels of abstractions, truthfulness or understanding (Figure 3.1). Information gives meaning to data through relational connection and knowledge is the collection of relevant or appropriate information thus supporting decision making (Toasa et al., 2018). In other words, there are a number of levels of transforming data to knowledge. Each level builds on the previous one; information is extracted from data, knowledge is gained from information through experience (Engelbrecht et al., 2015). At the knowledge level, the user is in a better position to make informed decisions based on data visualization.

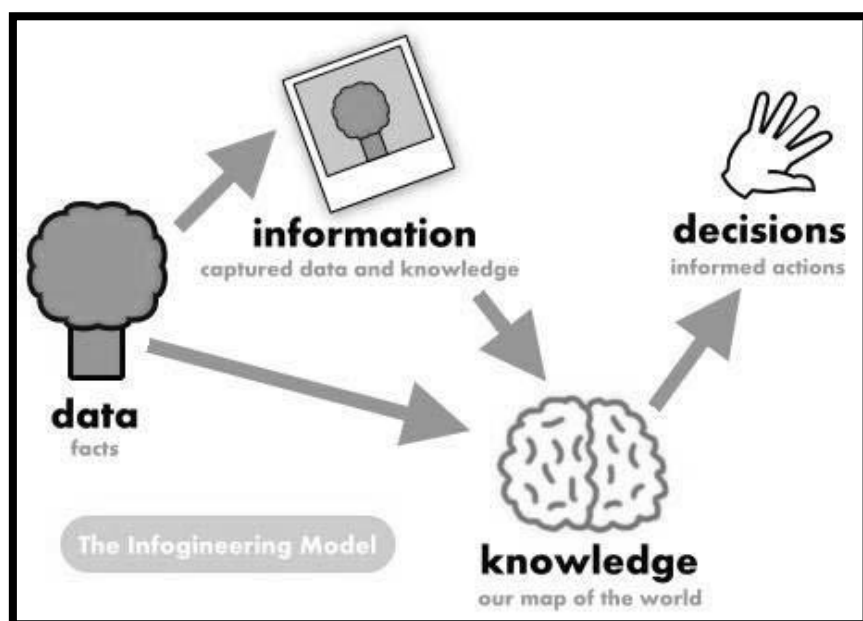


Figure 3.1 – Data, information, knowledge and decision (Toasa et al., 2018)

Data visualization can be defined as the ability to transform or process data, extract value from it, and visualize and communicate it (Chen, 2017a). It allows key messages found in large datasets to be presented (reported and interpreted) in simplistic form (Kemp et al., 2018). This is achieved through the combination of human intelligence and machine intelligence; human capabilities are embedded or incorporated into an intuitive visual interface (Chen et al., 2015). The definition of data visualization can be split into three parts (Azzam et al., 2013). “Data visualization is process that (a) is based on qualitative or quantitative data and (b) results in an image that is representative of the raw data, which (c) readable by viewers and supports exploration, examination, and communication of data”. Both quantitative (e.g. numeric values) and qualitative (e.g. pictures, drawings, video) require different methods or techniques of

visualization. The breadth and scope of visualizations should not omit information that is deemed important, biased, and reflect the data accurate (i.e. in its true form). Finally, the success of visualizations can be measure by its readability (supports examination, exploration, and communication); a visualization fails if it supports (a) and (b) but does not achieve (c). There are a number of data visualization benefits such as (Khan et al., 2017):

- Working memory expansion using visual aids that reduce cognitive load.
- Efficient space usage to visualize large amount of data reduces the effort of searching.
- Visually explicit presentations allow the discovery or identification of patterns.
- Large amount of data is aggregated to allow easy monitoring.

The main use of visualization is to obtain an understanding of data through exploration. A mental model (concept) is constructed through capturing (abstracting) the important features of data holistically, instead of listing data individually. For instance, building a concept of the fluctuation (i.e. increase or decrease) in temperature based on observed daily (or any other timeframe) temperature (Figure 3.2). Thus, a pattern (e.g. increasing temperature) can be identified by using this holistic approach. Sub-patterns can also be identified such as a wave repetition due to the decrease followed by an increase in temperature; therefore a “wave” is a composite pattern of the temperature fluctuations and the repetition becomes a high level pattern of “waves” (Purchase et al., 2014).

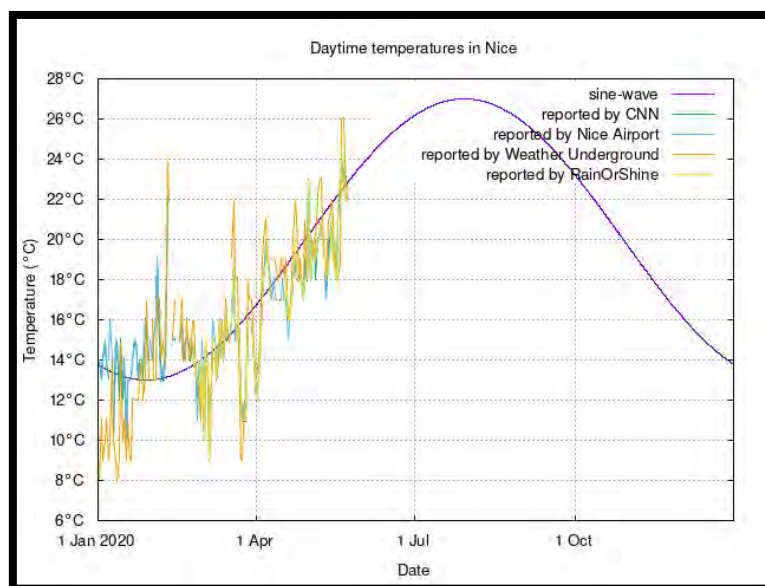


Figure 3.2 – An example of temperature fluctuation in Nice, France

(<https://www.w3.org/People/Bos/Nice/tempgraph>)

Traditional visualization techniques were developed for quick and accurate analysis and exploring data and were mainly used in statistics and science. In recent years, visualizations have expanded and are now being used by lay users too. Therefore, striking a balance between the science and the design (i.e. clarity/ information value and attractiveness/ aesthetics) of visualizations is imperative. This will allow the intended audience attracted to and understand the message portrayed by visualizations. Visualizations should be made attractive and clear for non-expert audiences; attractiveness is valuable but clarity is more important. Thus, information should be visualized “responsibly” to ensure that the user is not deceived by incorrect data – the message (visualization) should fit the data (Quispel et al. 2018).

Data visualization techniques range from simple charts (e.g. line and bar graphs) to advanced charts or techniques (e.g. scatter plot matrices and heat maps). Some of these techniques are harder to categorize due to specific use (purpose) design (Chen, 2017a). Common visualization techniques include line graphs, bar chart, scatter plot, pie chart. Literature advices against the use of pie charts for reasons such as the difficulty of comparing portions/ sections of the chart, and the user may become misled or confused (Sadiku et al., 2016). The following are some of the techniques and why they are used to visualize data (Jespersen, 2017) (Figure 3.3):

- **Line charts** – are for patterns over time.
- **Bar graph** – are for data relationships.
- **Bullet graph** – show data context in a small space.
- **Dot plot** – are for data measure comparisons.
- **Box plot** – shows multiple measures including the centre, shapes and spreads for comparison.
- **Scatter plot** – are for correlation between two variables or measures.
- **Spatial map** – are for showing physical location of data.
- **Heat map** – are shows data in different colours.

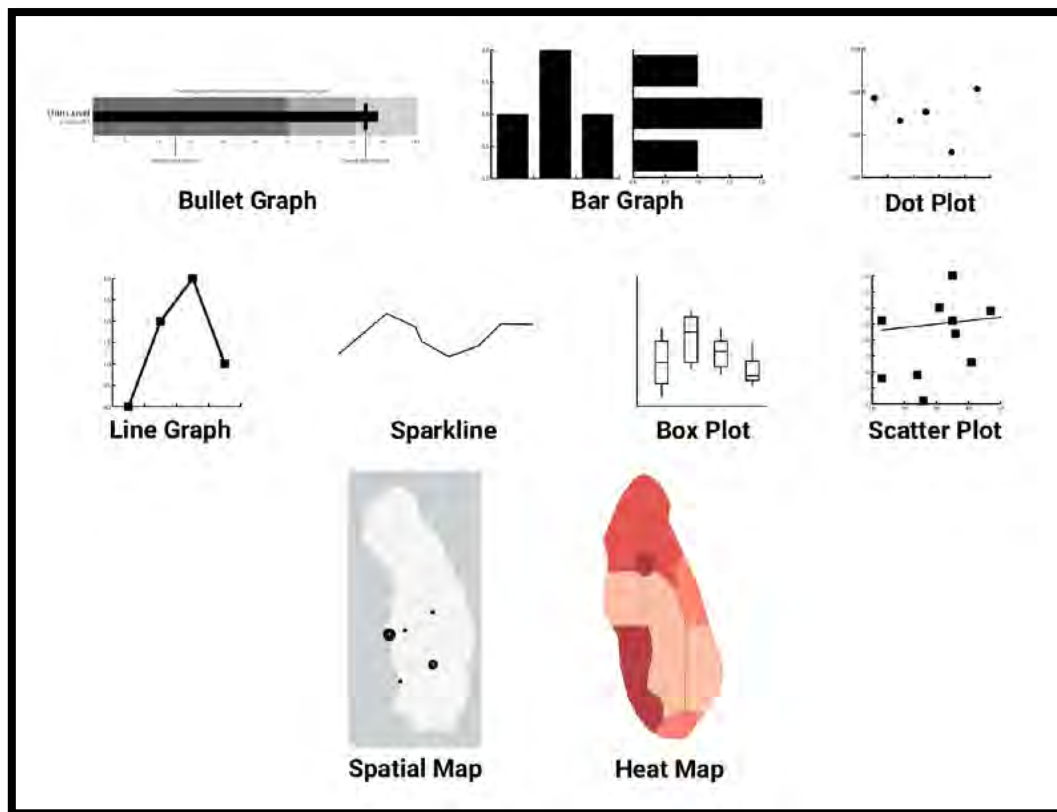


Figure 3.3 – Various data visualization techniques (Jespersen, 2017)

3.1.1. Visualization Typology

Various aspects need to be considered when transforming raw data into another format. Visualizations can be categorized by insight needs, data types to be visualized, utilized data transformations, interaction techniques, and visual mapping transformations (Börner et al., 2019). The visualization literacy framework has identified seven core categories (types) of visualizations (Figure 3.4) (Börner et al., 2019):

Insight needs	Data scales	Analyses	Visualizations	Graphic symbols	Graphic variables	Interactions
Categorize/cluster	Nominal	Statistical	Table	Geometric symbols	Spatial	Zoom
Order, rank, sort	Ordinal	Temporal	Chart	Point	Position	Search and locate
Distributions (also outliers)	Interval	Geospatial	Graph	Line	Retinal	Filter
Comparisons	Ratio	Topical	Map	Area	Form	Details on demand
Trends (process and time)		Relational	Tree	Surface	Color	History
Geospatial			Network	Volume	Optics	Extract
Compositions (also of text)				Linguistic symbols	Motion	Link and brush
Correlations/relationships				Text		Projection
				Numerals		Distortion
				Punctuation marks		
				Pictorial symbols		
				Images		
				Icons		
				Statistical glyphs		

Figure 3.4 – Visualization literacy framework typology (Börner et al., 2019)

- **Insight needs** – also known as “basic task types”, differ from one stakeholder to another. These needs should be understood to design an effective visualization for exploration and/or communication.
- **Data scales** – data variables have a number of scales (nominal, ordinal, and interval and ratio data) that determine the appropriate visual encodings and analyses that can be used. Nominal data supports equality checks with no ranking (e.g. job type), ordinal data assumes intrinsic ranking without measurable intervals (e.g. book chapters), interval data has an arbitrary zero point (e.g. temperature scales), and ratio data has a single non-arbitrary zero point (e.g. weight, length).
- **Analyses** – datasets are pre-processed, analysed or modelled before visualization. Analyse types include statistical (e.g. rank, order, sort), temporal - for “when” questions (e.g. trend discovery), geospatial – for “where” questions (e.g. distributions over space), topical – for “what” questions (e.g. examination of text composition), and relational analyses – for “with whom” questions (e.g. relationship examination).
- **Visualizations** – types include graphs, tables, charts, maps, networks, and trees. These visualizations can support the placement of data (records) through linkages. These visualizations use grid reference systems (e.g. tables) and continuous reference systems (e.g. geospatial map or scatterplot graph). One visualization can also be turned into another e.g. converting “*quantitative axes of a graph into categorical axes*” thus resulting into a table.
- **Graphic symbols** – these provide a visual presentation for data and can be classified as linguistic (numerals, text, and punctuation marks), geometric (line, point, area, volume, and surface), pictorial (icons, images, and statistical glyphs). These graphical symbols can be combined, for example, by placing a linguistic symbol label to represent a geometric symbol node.
- **Graphical variables** – can be organised as retinal and spatial (x, y, z position) variables. Retinal variables include texture (spacing, pattern, granularity, gradient,

orientation), colour (hue, value, saturation), form (shape, size, curvature, rotation, closure, angle), motion (speed, direction, rhythm, and velocity, flicker, style, traits) (Carpendale, 2003), and optics (shading, blur, stereoscopic depth, transparency). Graphic variables can be qualitative (no intrinsic ordering e.g. colour hue or shape) or quantitative (with different ordering directions e.g. cyclic, sequential, or diverging). The use of both graphical symbols and variables supports insight needs e.g. for identifying trends, outliers or clusters.

- **Interactions** – visualizations may be static such as printed or paper visualizations or allow dynamic manipulation through various interaction types such as searching, zooming, filtering, locating, extracting, details on demand, distortion, linking and brushing, history, and projection (Börner et al., 2019).

The first six categories (insight needs, data scales, analyses, visualizations, graphic symbols, and graphic variables) allow the data to be presented in a visual format; and the last category (interactions) provides a bit of functionality to the visualizations for further data examination/exploration (i.e. for further insights). Therefore, these categories encompass the elementary design features (i.e. visual and functional) of a dashboard, which makes data visualization invaluable for the design of dashboards.

Juiceanalytics (2010) presents a chart that summarizes different types of visualization techniques (Figure 3.5) and it combines some of the categories (typology) suggested by Börner et al. (2019).

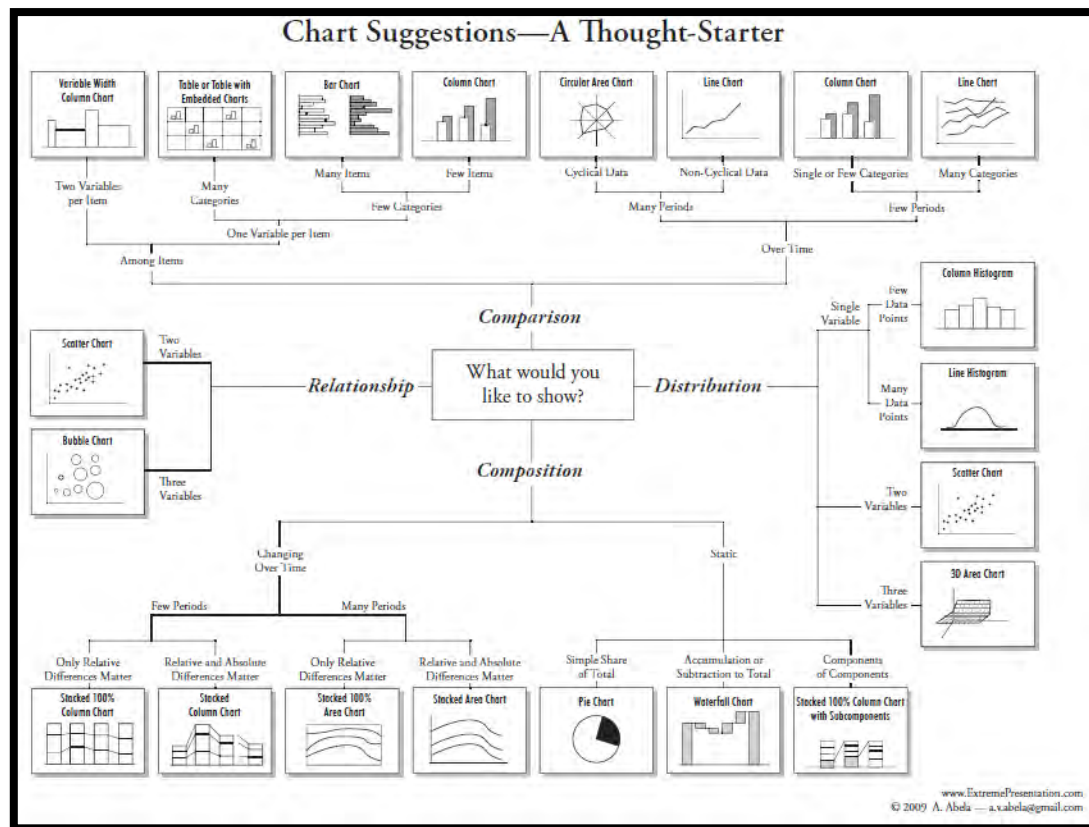


Figure 3.5 – Choosing the right chart (Juiceanalytics, 2010)

3.2. RELATED THEORIES

The field of visualization draws upon theories used in other disciplines such as graphic design, aesthetics, and psychology (cognition, perception and learning); it is almost impossible to have a single theory for information visualization. Data-centric prediction, scientific modelling and information communication are some of the theories that form the basis of visualization (Purchase et al., 2014). Theories are developed to capture regularities that provide a general view across diverse phenomena. Visualization field has several forms of theory such as (Liu & Stasko, 2010):

- **Laws** – are descriptive and provide regularities for instances of phenomena e.g. Fitts’s Law and Gestalt principles.
- **Models** – are concerned with mechanisms and procedures. Models can be in the form of stages or routines with interrelated steps e.g. information visualization reference model.

- **Frameworks** – are linked to philosophical connotations and theoretical work is based on assumptions. Visualization frameworks include cognitive aspect for understanding visual perception and cognition, and specification aspects.
- **Taxonomy** – for data, representation, interaction, and tasks in information visualization. Taxonomies characterize relationships between entries conceptually. An example is a taxonomy used for evaluating visualization that is discussed later in this chapter (Section 3.2.5).
- **Interpretation** – generalizations are not always possible in the complex and dynamic “human-world”, therefore; some theories are based on interpretation that brings forth novel perspectives.

Although this section covers not all theories, the relevant theories to this research will be discussed to provide suggestions (insights) that can inform the design of visualizations. The work done by Edward Tufte underpins a lot of recent work in visualization, therefore, some of the principles (guidelines) that are relevant to this research will be discussed first.

3.2.1. Edward Tufte’s Guidelines (Principles)

Edward Tufte who is the pioneer in information design field, proposed visual design principles that offered insights into presenting or visualizing information in a way that is effective and easy to comprehend (Chen, 2017b). Four essential guidelines are proposed by Tufte for visual information representation (Tufte, 1983):

GRAPHICAL EXCELLENCE

The users should be presented, in the shortest time, the maximum amount of ideas, using minimum ink, in the smallest amount of space. The Graphics should be used to communicate intricate ideas in an efficient, clear and precise manner. According to Tufte (1983), it should “show the data” at several levels of detail, be a true representation of the data (i.e. avoiding distortion) focus the viewers interest on the main idea instead of how the visual was created, entice the eye to move from one piece of data to another for comparisons, and serve the purpose (e.g. exploration).

VISUAL INTEGRITY

This is related to a “moral position”; this means the representations should not lead to misinterpretation or false impressions, and they should not distort the “truth” behind the data. Data graphics are regarded as similar to words; as means of communication that can be used for deception. Thus, data graphics should not distort the data in order to present the viewer with the underlying truth. The principles that can be followed include (Tufte, 1983):

- Representations should be directly proportional to the original data.
- Clear labelling and explanations of the graphics/data to reduce the distortion caused by representations.
- Prioritize data variation over design variation
- “Graphics should not quote data out of context”
- The dimensions contained in representation (i.e. graphics) should not be more than the number of dimensions found in the data.

MAXIMIZING THE DATA-INK RATIO

Data-ink is the amount of non-erasable, non-redundant part of the graphic. The majority of ink used on graphics should present data/information (i.e. not aesthetics); the ink should change when data changes. Data-ink-ratio is the amount ink (including aesthetics) that is required to unambiguously and clearly present data versus the actual amount of ink used to present data. Decorative, embellishments or superfluous elements should be minimized or removed (e.g. the use of unnecessary backgrounds, borders, 3D, colours etc.); this will ensure that representations do not distract the user while exploring the information. In other words, priority should be given to the data and not the visual appearance of representations.

Visualizations are regarded as means of communication therefore; information communication theory suggests that the “true” picture of data should be presented. This aligns and reinforces visual integrity principle proposed by Edward Tufte.

3.2.2. Information Communication

Visualization supports the user’s ability to understand the properties of the problem through transforming data into images. For more than two decades, data intensive applications have utilized visualization as a standard for undertaking data analysis. Visualization provides techniques for both spatial and non-spatial data. While visual analysis can be performed at an

ad-hoc (trial and error) manner, the rapid growth of data is increasing the difficulty of this ad-hoc approach. During the process of visualization, some important features of data may be left undiscovered due to the lack of quantitative metrics that provide a yardstick of the quality of visualized information. This is exacerbated by the fast growth of data. Thus, quantitative and systematic way is necessary for guiding users while they perform visual analysis. Information theory principles were developed by Wiener and Shannon (around the 1940s) to address the aforementioned issues (Shannon, 1948). Information theory focuses on the quality or reliability of messages that are transmitted through a noisy communication channel. Thus, it has been used in various fields such as computer science, physics, mathematics, art, electrical engineering, and economics (Wang & Shen, 2011).

Information visualization is regarded as a communication channel that allows the human observer to cognitively process a dataset (Figure 3.6). Thus, theories of data communication can assist in evaluating the effectiveness of visualization techniques. Information theory describes entropy as information lost during communication or transition. Measuring information loss is considered easier than measuring the total information that can be extracted in a dataset. For instance, multidimensional scaling can be used for measuring reduction of data dimensionality – “the difference between the distances between points in the original dimensioned space and the corresponding distances in the reduced dimension space” (Purchase et al., 2014).

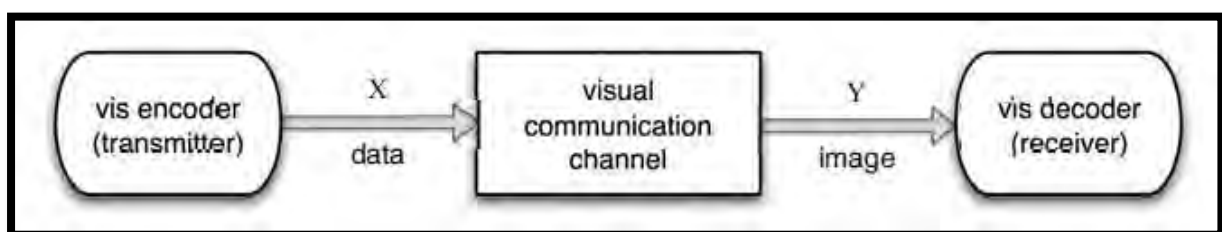


Figure 3.6 – Data visualization communication (Purchase et al., 2014)

The visualization process can be viewed as an information channel that visually communicates information from the data (source) to the user (viewer). In a visualization pipeline, a sequence of steps such as filtering, de-noising, projection, transform the data. These steps can be pictured as the encoding phase in the visualization pipeline that aims at extracting as much relevant information as possible for presenting it in the next phase of the pipeline. Special care is necessary for the selection of appropriate parameters from data for representing a true picture.

For example, the last angle (object on the right-hand side) on the Figure 3.7 shows a lot more/ maximum amount of information (e.g. edges, vertices, faces) that can be visually presented; it is better than the first two (Wang & Shen, 2011).

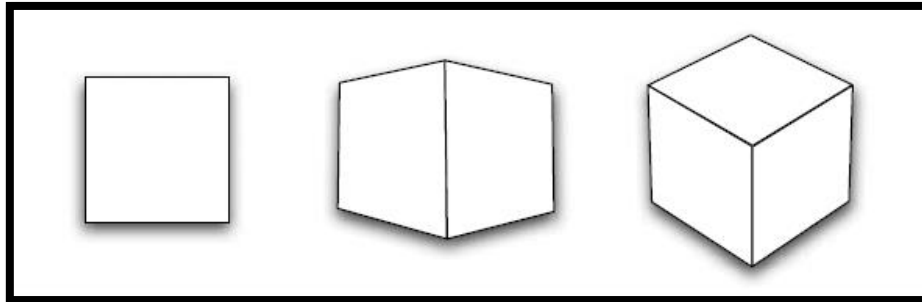


Figure 3.7 – Different views (presentations) of an object (Purchase et al., 2014)

The visualization process can introduce a certain degree of uncertainty to the user. Communication of information is not the end of the visualization process; the user also has to perform transformations (interpret) in the cognitive and perceptual mental space. Thus, attention to detail is necessary in translating data objects into visual objects by striking a balance between: a) information loss and visual quality and b) perceptual design principles and data fidelity. The visualizations should not be perceptually confusing, require much cognitive effort or suitable for expert users only. The information (values) presented should be easily identified and traceable (i.e. where values begin and end). Visualization techniques that are familiar with the user (fit the mental schema) should be used to present simple enough patterns to inform the user; the user should be able to determine what the information implies and what course of action to take (Dasgupta et al., 2012).

The next section will look at how users interpret, understand and make decisions based on visualizations or information that is “communicated” via representations.

3.2.3. Visual Perception

There are a number of ways human beings perceive things around them e.g. hearing, taste, smell, and vision. Vision is the most dominant sense due to its wide bandwidth – “the bitrate of consumed information capacity”. Vision is the most powerful and primary channel of input.

It captures the world and sends information to the brain for analysis. This sense vision is pre-attentive – the visual process takes place (happens) before the human interacts or attends to an object. During the visual search stage, information about the basic visual attributes or features of every single object is captured in parallel - through the sense of vision. Therefore, the careful selection, design, organization & presentation of data can take advantage of human vision to support data understandings and interpretations. This is valuable to human cognitive capacity and memory, which play a significant role in processing information (Chen, 2017a). The human visual perception is constantly scanning, adjusting focus, adapting, and it is relative. Human beings do not depend on the order of letters to read a word; placing the first and last letter correctly is enough for recognition. The brain takes care of processing visual information. For instance, a paragraph can have a number of spelling errors but humans can still comprehend without even realizing the spelling errors (Figure 3.8) (Chen, 2017b).

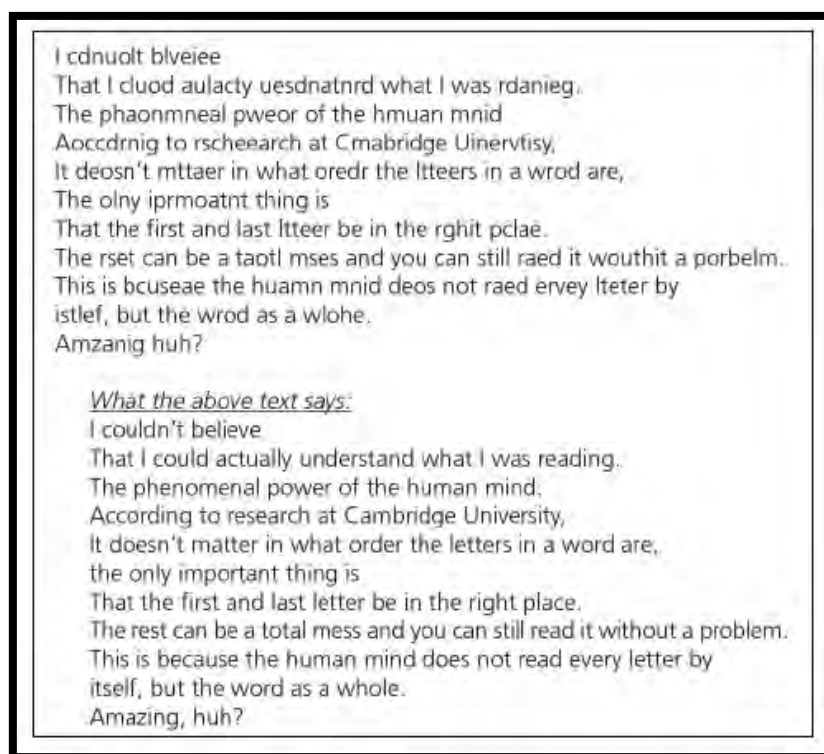


Figure 3.8 – A paragraph with spelling errors (Chen, 2017b).

Once the users have captured the “picture” through vision, they need to be able to process it. The next section explains how users process information as they capture/ view it.

3.2.4. Cognitive Fit Theory

Cognitive Fit theory suggests that comparisons between visual depictions and “learned graphical convention (mental schema) are made by the user. The theory suggests that an effective problem-solving process is influenced by the problem representation and the problem-solving task. In other words, the decision maker creates a “specific mental representation of the problem” due to the problem representation used while performing a problem-solving task. The fit between the problem representation and problem-solving task allows the user to create an appropriate mental representation of the problem thus increasing accuracy and reducing time of finding a solution to the problem. A mismatch is detrimental to the performance of the problems-solving process in terms of accuracy and/or speed (Teets et al., 2010).

This means that cognitive transformations are required if the users “mental schema” and the visualizations do not match. For instance, Figure 3.9 represents the relationship between a predator species and “Species X”. At the first glance of the image, most users would assume that the introduction of the predator species decreases the population of “Species X”. However, a closer look at the visualization shows an increase in the population. This is due to the user’s “mental schema” of the visualizations that have a Y-axis starting with a lower value near the X-axis line and a higher value towards the top of the Y-axis. Therefore, the visualization needs to be mentally rearranged (transformed) to fit the user’s “mental schema”. The issue is that the steps involved in the transformation process increase errors, task completion time, and working memory requirements. Therefore, visualizations used should reduce the chances of mismatches occurring through demanding lesser number of transformations during decision-making (i.e. more intuitive and require less cognitive effort). Visualizations should match the task to reduce the number of transformation e.g. table for specific values and graphs for comparisons (relationships) (Padilla et al., 2018).

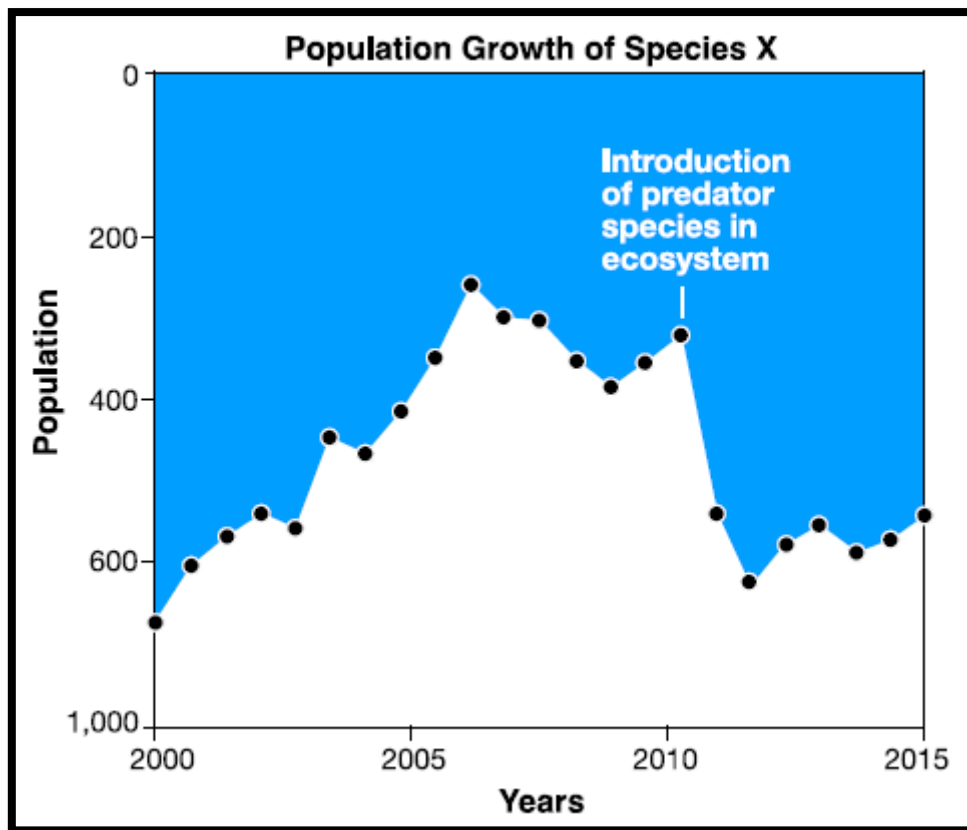


Figure 3.9 – Effect of a predator species on the population growth of Species X (Padilla et al., 2018)

There are two decision-making tasks: symbolic and spatial. Symbolic tasks are for specific or discrete value extractions through analytical processes; using a table would create a better “fit” for symbolic tasks. Spatial tasks requires associations or relationships to be perceived from the data to allow the decision maker to view (evaluate) the problem area holistically; using a graph would create a better “fit” for spatial tasks (Teets et al., 2010). Therefore, understanding the users’ tasks is important for data visualization.

Once the user is able to interpret the visualization, the user needs to make an informed decision. Padilla et al. (2018) presents a framework that explains the process that the user follows to make visualization-based decisions.

3.2.5. Dual-Process Cognitive Framework

There are many decisions made through the support of visualizations such as medical treatment decisions, driving route selection etc. These visualizations are “*external visual representations that are systematically related to the information that they represent*” (Padilla et al., 2018). Dual-process is a decision-making framework that has been used for years. The framework proposes two categories (types) of decision processes: Type 1 decisions – are regarded as fast, easy (computationally light), require less working memory resources (“controlled attention”) and happen unconsciously (automatic decisions); and Type 2 decisions are effortful, slow, and contemplative. Human can make both intuitive and strategic decisions; the “dual-process” represents these decisions as Type 1 and Type 2 decisions (processes). These two decision types are not mutually exclusive (e.g., Type 1 decision or rules of thumb can influence the Type 2 decisions of a visualization viewer). Working memory is a “*multicomponent system that holds information temporarily and mediates its use in ongoing mental activities*”. Information is temporarily held in the working memory without storing it into the long-term memory. Visualizations that require a lot of working memory (Type 2) are the ones that depend on the working memory to conduct conscious processes (“*depend on the deliberate application of working memory*”) for decision-making (Padilla et al., 2018).

A model is proposed to show how a “*visual array, defined as the unprocessed neuronal firing in response to visualizations, bottom-up encoding mechanisms are utilized to construct a **visual description**, which is the mental encoding of the visual stimulus*” (Padilla et al., 2018). The users then use their long-term memory to interpret the visualization; the long-term memory contains knowledge in the form of visualization schemas. The visual array is **matched** to the visualization schema. The schema is **instantiated** when a matching visualization schema is found. “The visualization conventions associated with the graph schema can then help the viewer interpret the visualization (message assembly process)”. The Figure 3.10 shows how a bar chart is comprehended. The matched visualization (graph) schema for a bar graph suggests that the independent variable is on the X-axis and the dependent variable is on the Y-axis; the instantiated visualization (graph) schema combines the additional information and the visual description. A **conceptual message** (“the mental representation of the visualization”) is developed that include the additional information from the long-term memory and further mental transformation made on the visualizations. The **conceptual question** related to the user’s task (e.g. what is the average between A and B? Is it closer to 2 or 2.2?), triggers

transformation of the visualization-mental-representation through **interrogation** – this process answers the conceptual question. The working memory is also used to answer the conceptual question. There are a number of top-down encoding mechanisms may influence the processes at any stage (Padilla et al., 2018).

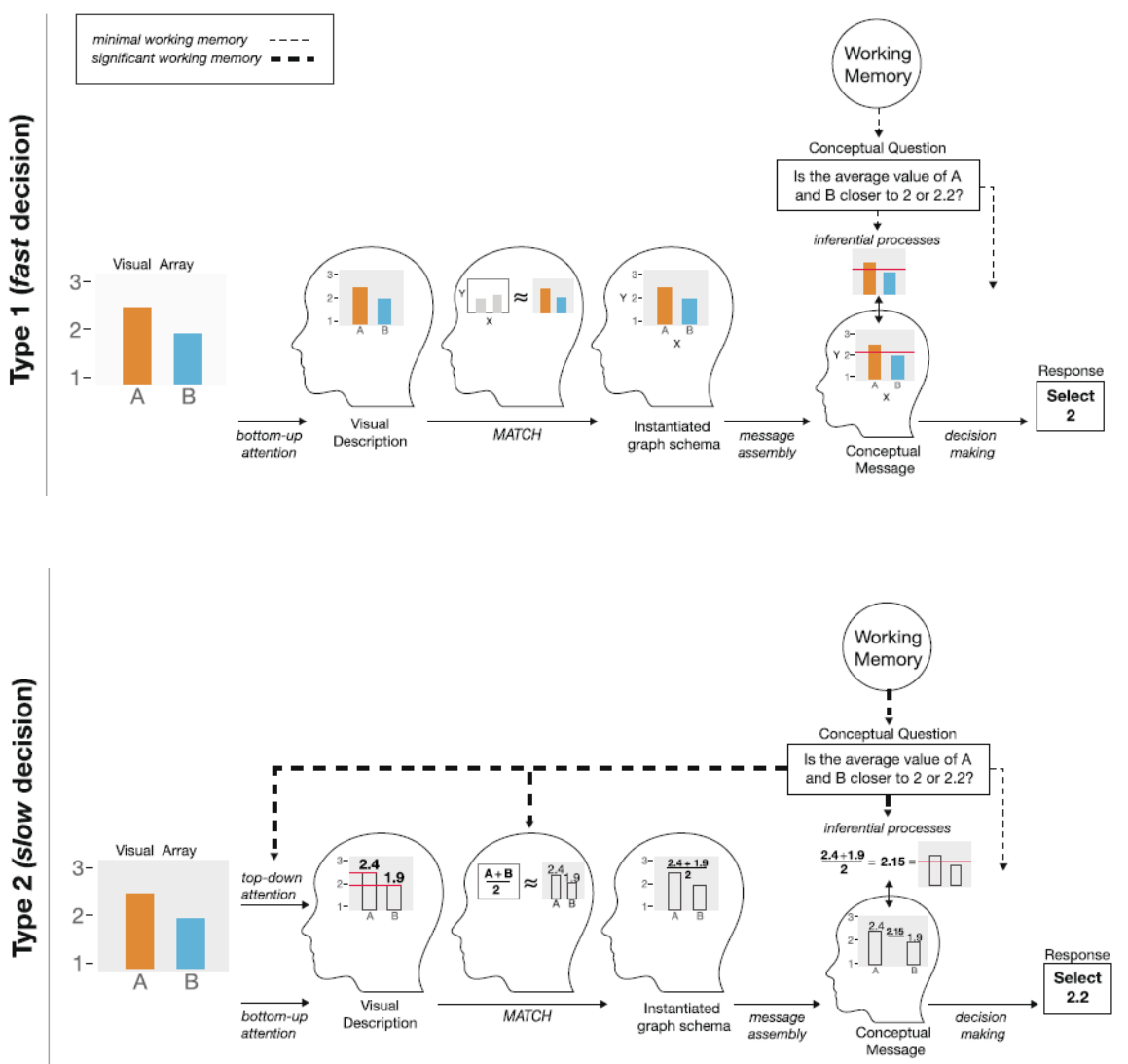


Figure 3.10 – Type 1 & Type 2 Decision process (Padilla et al., 2018)

The dual process account of decision-making is introduced in this model. When users make visualization-based decisions using less amount of working memory, this is classified as Type 1 thinking. The complexity of the decision-making tasks determines the amount of working memory capacity required for effective performance (of the tasks). Going back to the conceptual question or task of determine the average and if it is closer to the value 2 or 2.2. A Type 1 (fast and computationally light) decision would lead the user believe the average is

closer to 2, due to the middle point of the two bars being closer to “the salient tick mark of 2”. On the other hand, a further analysis (Type 2) through using more working memory and knowledge (i.e. a method that was learned for solving similar problems”) allows the user to make the actual computation – $2.4 + 1.9/2$ – concluding the answer as 2.2 (Padilla et al., 2018).

Type 1 process (working memory is not utilized) focuses the user’s attention (involuntarily) to salient features of the visualization. The salient features (information) draw the user’s attention to the visualization thus missing non-salient information (creates a bias and if used poorly the user may focus on irrelevant information). The user spends most of the time looking at the salient information. Therefore, it is important to use saliency appropriately to draw attention to task relevant information. For instance, a study shows that users would pay more (+ \$125) for tires with 0.0000003 amount of improvement due to the focus on icons and missing a base rate (5,000,000) written in text. The decision is made based on the differences between the icons of both tires, which makes the difference seem as if it is significant (i.e. more than 0.0000003) (Padilla et al., 2018).

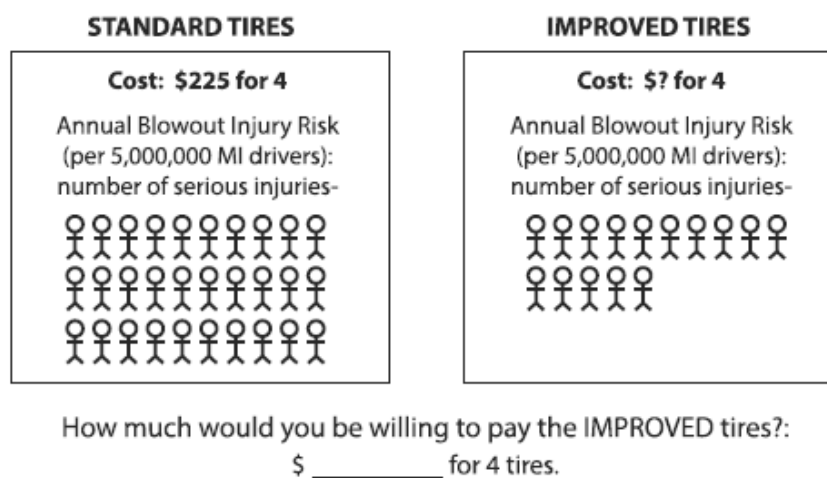


Figure 3.11 – Visualization of an improvement made on tires (Padilla et al., 2018).

The goal of this research is to mainly support “Type 1” decision process to ensure that visualizations are more intuitive and “fit” with the user’s mental model, instantly (at first glance). This section provided an essence of how users make visualization-based decisions. Although the effects of individual factors are beyond the scope of this research, they also suggest that visualization should be designed to cater (accommodate) for majority of users (who often have different preferences).

3.2.6. Individual Factors

Visualizations tools provide “external knowledge” related to an intricate analytical domain or task and they support thinking – they embody the process of reasoning through interactions with the visualizations. Thus, it is important to understand how various users think while using visualizations. Perceptual visualization theory explains and models low-level (fundamental) tasks that users perform. Users are becoming dependant on using visualizations, as cognitive support, for solving difficult or complex problems. However, users are different in many ways due to their personality, experiences, and cognitive abilities etc. that determine the way these users understand the problem domain and solve related tasks. It is nearly impossible to design a special visualization for each user; therefore, understanding various users (groups) can inform the design of visualizations. It is important note that the cognitive style of each user, together with the visual design, influence the value of visualization (Ziemkiewicz et al., 2012).

COGNITIVE FACTORS

Individuals are different in terms of their working memory, perceptual abilities, verbal ability and spatial ability; these cognitive factors influence reasoning. For instance, perceptual and spatial abilities (e.g. spatial orientation, perceptual speed, and visual memory capacity) affect the accuracy and response time of the user during completing tasks that require the user to understand 2D and 3D visualizations. A study shows that users with higher spatial ability can produce “more accurate cross-sections and visualizations, while those with low spatial ability rarely discovered the best view from which to create the cross section”. Therefore, the design of visualizations has to consider the users’ different cognitive abilities that influence the different strategies or approaches to performing the same task (Ziemkiewicz et al., 2012).

PERSONALITY FACTORS

The users’ personality differences have an impact on their performance; personality has the strongest effect on performing complex tasks due to a higher-level of reasoning required. The Five-Factor model of personality traits (i.e. extraversion, agreeableness, neuroticism, conscientiousness, and openness to experience) that is widely used, can inform the design of visualizations. For instance, a study on these personality factors showed that users with introversion preferred a blue theme; conscientiousness preferred a yellow theme; and imaginative users preferred a black theme. However, these preferences only indicate the adoption of visualizations. Performance was studied on personality factors (e.g. locus of

control); this was done by shifting orientation from a list view (visualization) to a view that uses a containment metaphor. The results showed that the differences in the participant’s personalities affect the use of visualization (although the relationship is not straightforward); “cognitively demanding situations” such as metaphorical reasoning and inference increase the value of visualizations (Ziemkiewicz et al., 2012).

The combinations of the users’ cognitive and personality factors are limitless; therefore, visualizations (interfaces) need to be adaptive. Therefore, mechanisms for designing adjustable visualizations (interfaces) to fit the individual user can influence the performance of task completion (Ziemkiewicz et al., 2012). Customization according to individual factors (e.g. personality traits) may lead to the successful use of visualizations in dashboards (Yigitbasioglu & Velcu, 2012).

3.3. DESIGN PROCESS

In order to transform data into a more interpretable format, Chi (2000), Khan et al. (2017), and Börner et al. (2019) suggest design processes that can be followed. Chi (2000) suggests a visualization data pipeline that has four stages: “Value, Analytical Abstraction, Visualization Abstraction, and View” (Table 3.1). Data transformation operators are used to transform the data from one stage to the next: Data Transformation, Visualization Transformation, and Visual Mapping Transformation (Table 3.2). The transformation process of the different data states is depicted in Figure 3.12.

Table 3.1 – Data Stages in the Data State Model

Stage	Description
Value	“The raw data.”
Analytical Abstraction	“Data about data, or information, a.k.a. meta-data.”
Visualization Abstraction	“Information that is visualizable on the screen using a visualization technique.”
View	“The end-product of the visualization mapping, where the user sees and interprets the picture presented to her.”

Table 3.2 – Transformation Operators

Processing Step	Description
Data Transformation	“Generates some form of analytical abstraction from the value (usually by extraction).”
Visualization Transaction	“Takes an analytical abstraction and further reduces it into some form of visualization abstraction, which is visualizable content.”
Visual Mapping Transformation	“Takes information that is in a visualizable format and presents a graphical view.”

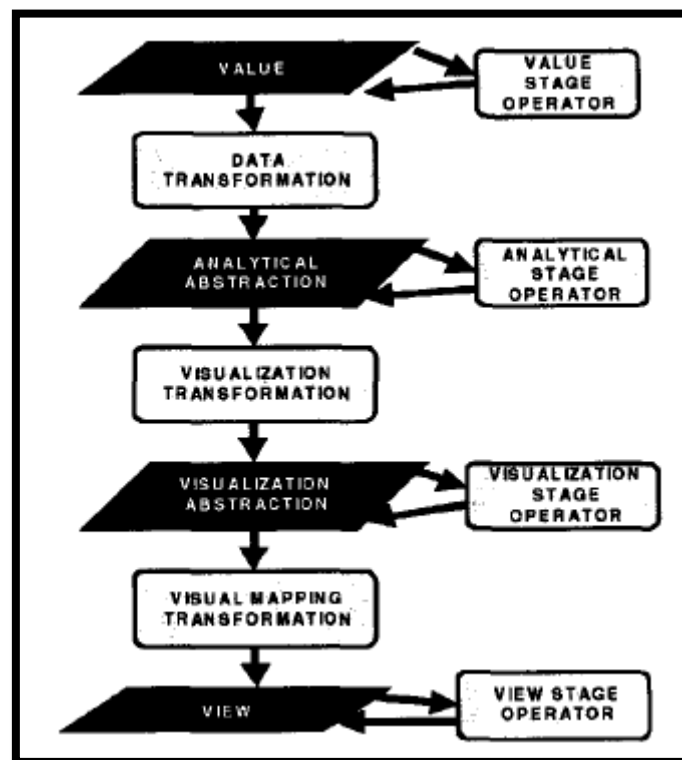


Figure 3.12 - Information Visualization Data State Reference Model (Chi, 2000)

Similarly, Khan et al. (2017) provide seven phases of data visualization that are not linear in nature (Figure 3.13).

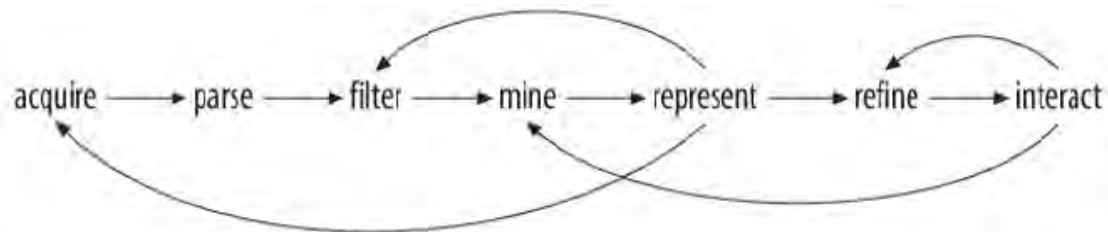


Figure 3.13 – Data visualization process (Khan et al., 2017)

They can be fit into Chi's (2000) transformation operators (processing steps) as follows:

DATA TRANSFORMATION

- **Acquiring** – raw data is pooled from all available resources.
- **Parse** – data is converted (parsed) into meaningful categories.
- **Filter** – relevant data is selected by discarding irrelevant or unnecessary data.
- **Mine** – statistics and data mining techniques are used to generate patterns before visual analytics can begin.

VISUAL TRANSFORMATION

- **Represent** – basic visualization techniques (e.g. lists, charts, or trees) are used to represent data.

VISUAL MAPPING TRANSFORMATION

- **Refine** – the basic representations are improved through a clearer and comprehensive visualization.
- **Interact** – the user interacts and manipulates the data features (system).

Börner et al. (2019) present a similar process model. There are a number of steps that are involved in the construction and interpretation of data visualization (Börner et al., 2019). The cyclic process begins with identifying the **stakeholders** and their needs. The stakeholder present textual and verbal descriptions of the “real-world” problem that needs to be transformed into a data visualization; this allows the “appropriate datasets, analysis, visualization workflows, and deployment options’ to be determined. **Acquire** – relevant datasets are acquired based on well-defined needs of the stakeholder. **Analyse** (combines parse, filter, mine; data transformation) – pre-processing data may be necessary and includes steps such as data cleaning (e.g. deduplication of data, anomaly and error corrections etc.), data transformation (e.g. network extraction, aggregations, geocoding), and statistical, topic, temporal, geospatial or relational network analyses. **Visualize** (combines represent and refine; visualization and visual mapping transformation) – this step can be categorized in to two activities: choosing a

reference system and design data overlay. The former deals with choosing a visualization type and the latter deals with mapping data records (variables) to graphic symbols and variables. Figure 3.14 also shows a US map reference system with added graphical symbols (e.g. circle, lines) and variables (e.g. size, colour). **Deploy** – there are different deployments that support different interactions such as printing in 3D or on paper, an interactive display (e.g. on a handheld device), virtual reality headset etc. interface controls such as menus, buttons, tabs for selection; zoom and sliders for filtering; double click and hover for details on demand; support a diverse range of interactions. **Interpret** – the users (stakeholders) need to be able to read and interpret the visualization. The whole process involves turning visualization results into stories and insights that can affect (i.e. be applied in) the “real-world” (Börner et al., 2019). Figure 3.14 combines the typologies and the process.

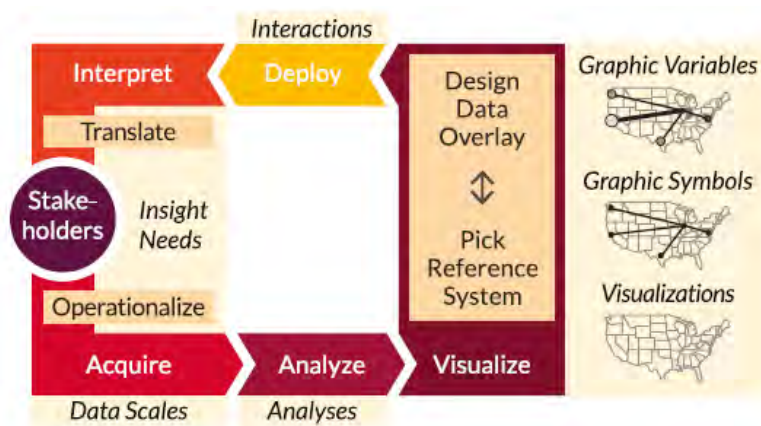


Figure 3.14 – Process steps and typologies (Börner et al., 2019)

3.4. EVALUATION

Visualizations need to present data effectively; therefore, a way of finding problems related to communicating data through visualization and addressing them, ensures that the visualizations are designed the best way possible. To ensure that data is visualized (“encoded”) and interpreted (“decoded”) effectively, Dasgupta et al. (2015) suggests a taxonomy based on the work of Shannon (1948), Chi (2000), and Dasgupta et al. (2012) that can assist the evaluation of visualizations through addressing various “design problems”; thus improving the quality of the visualization design. A traditional information pipelines was used to categorize the problems into the encoding and decoding phases of the user’s cognitive and perceptual processes and a hierarchy of levels that allow the design problems to be systematically analysed.

- **Problem stage:** This level determines whether the design problem falls under the encoding or decoding stage. *Encoding* is related to the decisions and choices made by the designer concerning transforming data points into visual features. Thus, problems found at the encoding stage ensure that the encoding strategy is guided by best practices. *Decoding* “captures design problems that go beyond the specific scope of visual encoding and the deliberate encoding choices a designer makes”. Design problems affect how users can effectively decode the information that is presented.
- **Problem type:** classifies the problem in a number of types based on its characteristics; it encapsulates the low-level causes. This level reveals exposes the gaps of the encoding process (e.g. shows whether the appropriate visual mappings and chart types used). It is worth noting that not all conditions have to be fulfilled in order for the visualization to be used. On the decoding side, this level reveals the complexity of the visuals, level of distortion of information or cluttering.
- **Cause of problem:** This shows the exact problem and shows the low-level details of where it lies.

ENCODING STAGE

During this stage, it is important to determine the chart, visual variable, level of detail and colour map appropriateness (Figure 3.15).

Chart appropriateness

The designer has to decide on the chart that should be used. The chosen chart should reflect “intent”. Thus, the chart is analysed for its limitations.

- **Mismatch:** this relates to the mismatch of the visual presentation chosen and the intent based on the inherent limitations of the visual representation.
- **Configuration:** this reveals problems associated with arranging more than one chart on a single (common) canvas (e.g. stacking multiple charts without ordering according to similarity).

Visual variable

This is an important design decision that relates to the choice of visual variables used to map data attributes. The number of visual variables (e.g. shape, position, colour, and orientation) is a lot less than the number of data attributes; the former should be used effectively when designing visualizations.

- **Choice:** The chosen visual mapping should prioritize and “show the data” (e.g. the use of colour to represent qualitative data).
- **Ambiguity:** the visual variable use should not confuse the user (e.g. using different visual variables for representing the same data attribute, or the same visual variable for representing different data attribute). This can lead to misinterpretation; relationships may be found where there are non-existent or identification of a single relationship where there is more than one.

Level of detail

The appropriate level of detail should be chosen to ensure the “intent” is communicated properly and data is precisely presented.

- **Granularity:** a choice between finer or coarser granularity should be made to ensure the main message is conveyed (e.g., low-level granularity would allow a sequential search for relationships – similarities or dissimilarities – however, the user may miss the overall trends).
- **Jaggedness:** the choice of level of jaggedness of lines used in graphs should be made (e.g. smoothing to show the main trend).

Colour map

An appropriate colour map is should be selected to allow the data to be presented and analyses effectively. Colour maps used for qualitative data (attributes) assist category identifications and allow accurate judgement of quantitative data (attributes).

- **Quantitative mapping:** appropriate mapping should be used to avoid problems such as using a rainbow colour map, which may cause misinterpretations due to lack of “perception ordering”.
- **Qualitative mapping:** colour mappings used should reflect qualitative attributes by using contrasting hues for representing discrete variables.

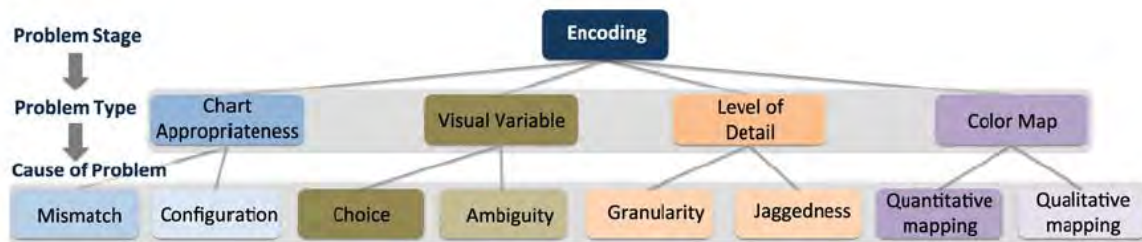


Figure 3.15 – Encoding stage (Dasgupta et al., 2015)

DECODING STAGE

The perceptual implications need to be analysed in order to assess (judge) the quality of visualizations. This section provides areas that need to be examined (assessed) (Figure 3.16).

Cluster

This involves the “degradation of the display” due to the organization, representation and number of items.

- **Colour missing:** this relates to using multiple colours for chart elements, symbols, and the background. This may lead to obstruction of important information.
- **Overlap:** means over-plotting of data items e.g. thick crossing lines in line charts. Overlaps or over-plotting can be valuable if used in a manner that does not interfere with the “intent” of the visualization.

Distortion

This can lead to misinterpretation (wrong perception) of data; especially for quantitative attributes.

- **Scale inconsistency:** the scale chosen to represent the same variable should be uniform (consistent) to avoid misleading the user.
- **Projection error:** is typically found in maps during transforming a “3D sphere into a 2D surface”. Therefore, better projection technique selection is important.

Comparison complexity

This deals with design problems related to the number of data points per chart, number of charts per view, or their placement.

- **Superposition overload:** too many entities in a chart make it difficult to make comparisons. This can also lead to cluttering within a visualization thus “interfering with intent”.

- **Lack of explicit encoding:** this makes it difficult for comparisons to be made between entities. For optimization of visual search, the positioning and sequencing of individual charts should be considered.

Communication gap

Although not related to intent, this is about problems that might make communication of patterns difficult. Auxiliary information may be added to charts for better communication.

- **Grids:** make visualizations intuitive through “chunking important pieces of information”. Although unnecessary gridlines should be avoided (chart junk), the smallest changes in graphic layouts can allow an immediate impression to be made and for the overall message to be communicated effectively.
- **Legend:** these give meaning to various symbols used to charts; lack of legends could lead to the user browsing textual descriptions back and forth to understand the symbols.
- **Annotation:** adding annotations to important patterns is valuable for communicating the main message or “intent”

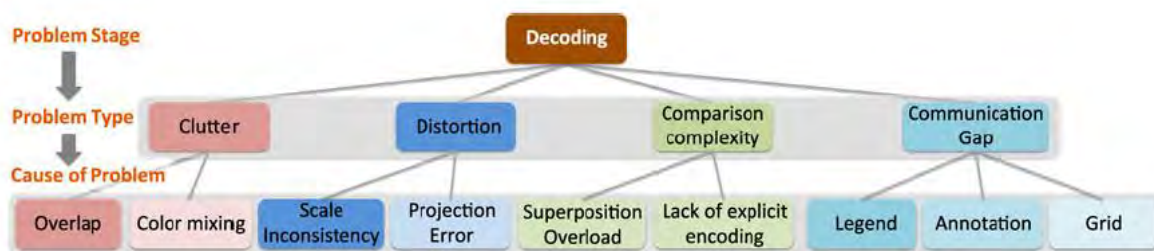


Figure 3.16 – Decoding stage (Dasgupta et al., 2015)

The consequences of various problems identified in visualizations are summarized in Figure 3.17. A trade-off should be made when designing the visualizations because a perfect visualization is not easily achieved. The intent or purpose of the visualization should guide the design. In other words, addressing these problems will ensure quality visualizations are design (i.e. that will be easily interpreted).

Causes of Problem	Consequence
Visual variable problem: <i>ambiguity</i> Distortion: <i>scale inconsistency</i>	Misinterpretation
Distortion: <i>projection error</i> Distortion: <i>scale inconsistency</i> Color map: <i>quantitative mapping</i>	Inaccuracy
Chart appropriateness: <i>mismatch</i> Chart appropriateness: <i>configuration</i> Visual variable problem: <i>choice</i> Level-of-detail: <i>jaggedness</i>	Lack of expressiveness
Visual variable problem: <i>choice</i> Level-of-detail: <i>granularity</i> Color map choice: <i>qualitative mapping</i> Clutter: <i>color mixing</i> Clutter: <i>overlap</i> Comparison complexity: <i>superposition</i> <i>overload</i> Comparison complexity: <i>lack of explicit encoding</i>	Inefficiency
Communication gap: <i>grids</i> Comparison complexity: <i>lack of explicit encoding</i> Communication gap: <i>grids, legend</i> Communication gap: <i>annotation</i>	Lack of emphasis

Misinterpretation has the highest degree of severity owing to the misrepresentation of the intent. Lack of emphasis is least severe as the problems are dependent on the inefficiency of the visual communication process, and not the incorrectness of the representation.

Figure 3.17 – Consequence of design problems (Dasgupta et al., 2015)

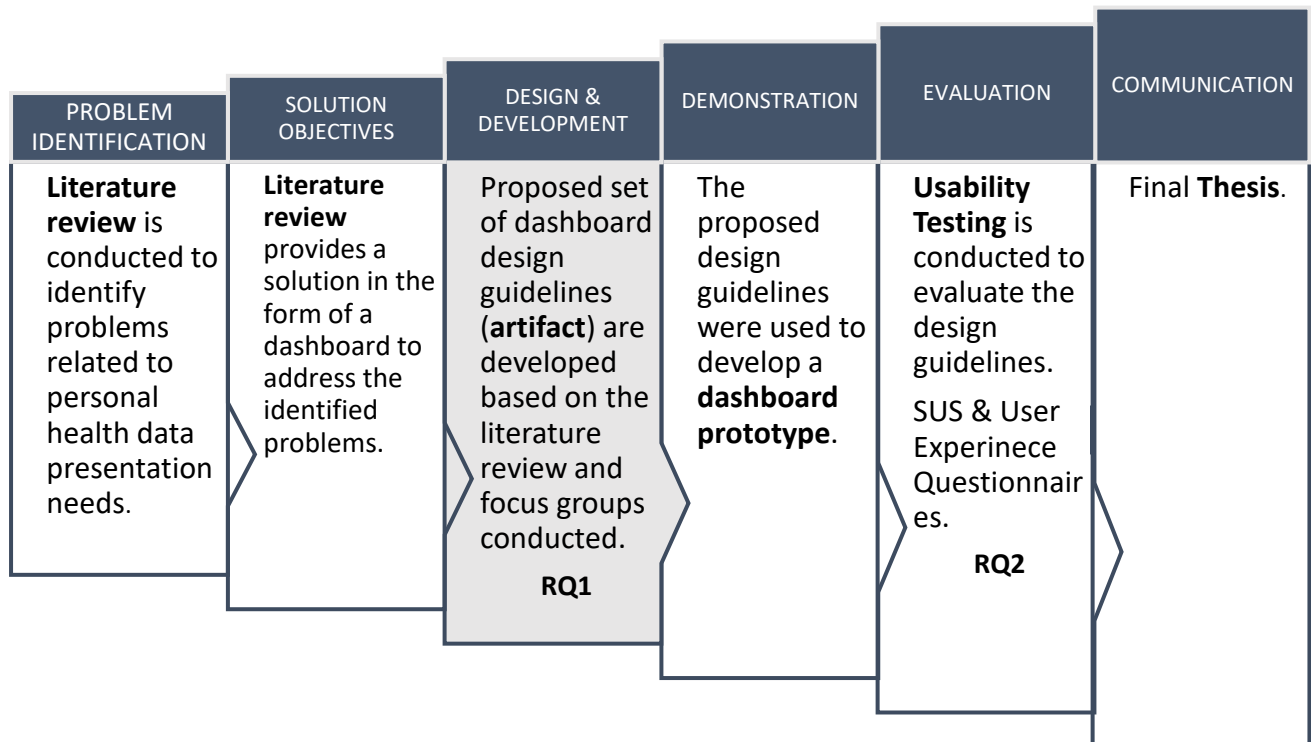
3.5. CONCLUSION

This chapter has provided insights (clues) on what data visualization is, how it is used, and how it affects the users and their decisions. Related theoretical literature (e.g. information communication, cognitive fit, visual perception) was weaved together and outlined in terms of considerations that should be kept in mind while designing visualizations for users. Therefore, for effectively presenting data, all aspects mentioned in this chapter are imperative to ensure that the “visualization” are intuitive and easily understood (for supporting decisions). The reason for detailing on data visualization is that it forms the rudimental part of a dashboard; without it, the dashboard will not present data effectively. Design aspects that were discovered in this chapter fall under the following areas: personalization, customization, cognitive fit theory, minimizing the data-ink ratio, data context, visual integrity, multiple window layout,

symmetry and proportion, details on demand, principles of visual perception, appropriate data medium, graphical excellence, and visualizations should be neat. These areas are valuable for designing visualizations that can be easily understood or interpreted by a wide range of users.

CHAPTER 4:

DASHBOARDS



A dashboard integrates data application, the user interface, and visual views. In other words, dashboards use visualization to communicate information on a user interface (“*Dashboard = Data + Visualization + UI*”) (Yigitbasioglu & Velcu, 2012; Zheng, 2017). This chapter will provide a background to dashboards in general; then the holistic design will be broken down into the fundamental design features (i.e. visual and functional); lastly, design principles, and important themes around the make-up of a well-designed dashboard will be discussed.

4.1. OVERVIEW

Dashboards visualize important data to inform decisions. They are created for presenting various types of data to obtain specific goals or targets (Rouhani et al., 2018). A dashboard should support the organization goal without distracting the viewer and present relevant information for the “current task” (Abd-Elfattah et al., 2014). An example of a dashboard is presented in the Figure 4.1 (Janes et al., 2013).

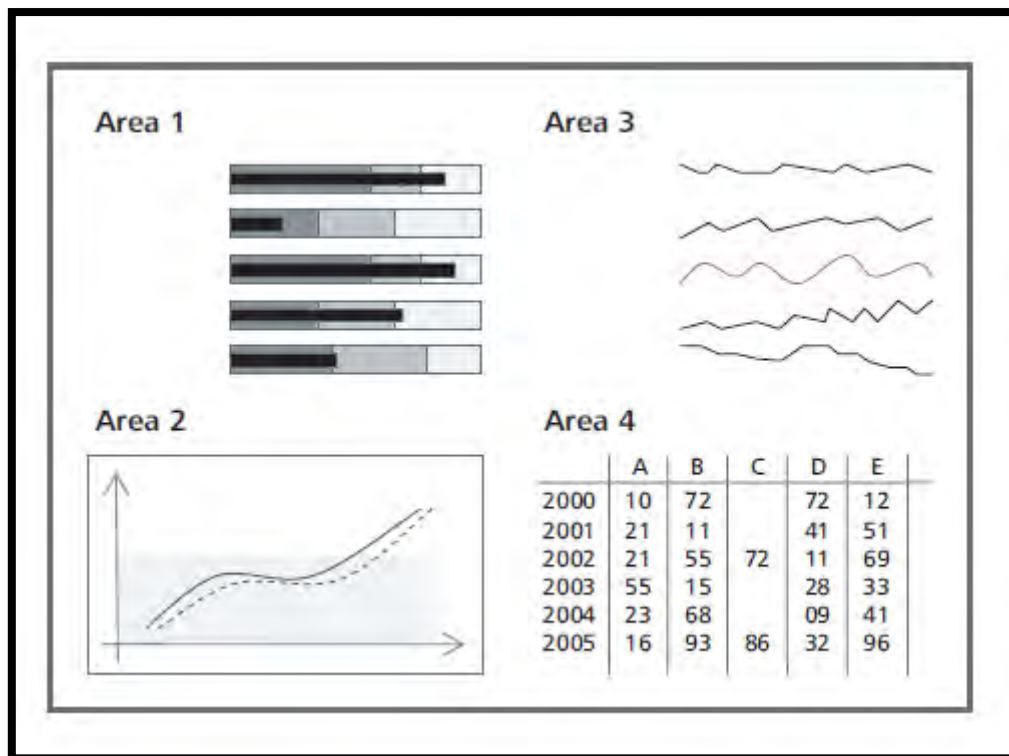


Figure 4.1 – An example of a “typical” dashboard (Janes et al., 2013)

Dashboards are regarded as a use case for data visualization; as stereotyped by the visualization community. They offer a display of visual information for users to monitor current conditions quickly and to respond or act when necessary. They have evolved from “single-view reporting screens” to interfaces that offer interactivity and multiple views. In other words, they offer a visual representation of data through a tiled layout of charts, and functional aspects (e.g. for customizing the dashboards, filtering data, and modifying the state of data) that offer display interactivity (Sarıkaya et al., 2019). They are not static only; they can be updated depending on the users’ demands and the system’s capability (Abd-Elfattah et al., 2014). Gunapati (2011) categorizes dashboards as either static or dynamic:

- **Static dashboards** (e.g. printed reports; online pdf files) present information for a specific timeframe. They do not offer interactivity and cannot be regularly updated.
- **Dynamic dashboards** (e.g. web-based) are interactive (allow manipulation) and can extract live information stored in various data sources. Dashboards based on regularly updated data sources can also provide real-time information.

A dashboard presents information in graphical form through a “rich” user interface of various elements (e.g. charts and graphs). These elements allow the user to analyse large and complex volumes of data for effective decision-making (Hansoti, 2010). Since the complexity of high volumes of data makes decision-making and problem solving harder, dashboards provide a means of displaying information that makes it easier for the users to explore relevant data and analyse the root of the problem in a timely manner. This in turn supports collaborations and decisions, reducing oversight, and improving work efficiency. They improve the user’s ability to remember and interpret data easily; thus, reducing the user’s cognitive load (Rouhani et al., 2018). However, it is important to note that the information presented on the dashboard should be neutral. It should present the truth not the designer’s perspective and bias, otherwise, the information will mislead the users. All information presented through a dashboard is interpreted as definitive and trustworthy by the users (Sarikaya et al., 2019).

A dashboard needs to present an overview of important information clearly and rapidly. It should put the information into context (i.e. include meaningful comparisons), display the information based on correct and reliable data, and communicate the information clearly and accurately on a single screen. The dashboards (and the underlying technology) do not think – people do. Therefore, the dashboard should present information accurately, clearly and rapidly in order for the users to make connections, detect patterns and recognize implications from the information (Few, 2006). Conclusions will “hit the users between the eyes” if the dashboard is designed effectively. To be effective they should support the following activities (Few, 2006):

1. Provide a consolidated overview of information to allow users to identify the information that needs their immediate attention.
2. Provide enough information to allow the user to determine whether further investigation is required.
3. Allow further investigation by providing details (additional) on the information that demands the users’ attention; thus, allowing them to determine the appropriate course of actions.

Therefore, information should be presented on a single view (excluding supporting detailed information for later). Figure 4.2 shows how the activities above allow a user to find relevant information; the user “scans” the holistic view of information and drills down to specific information for data-driven decision-making.

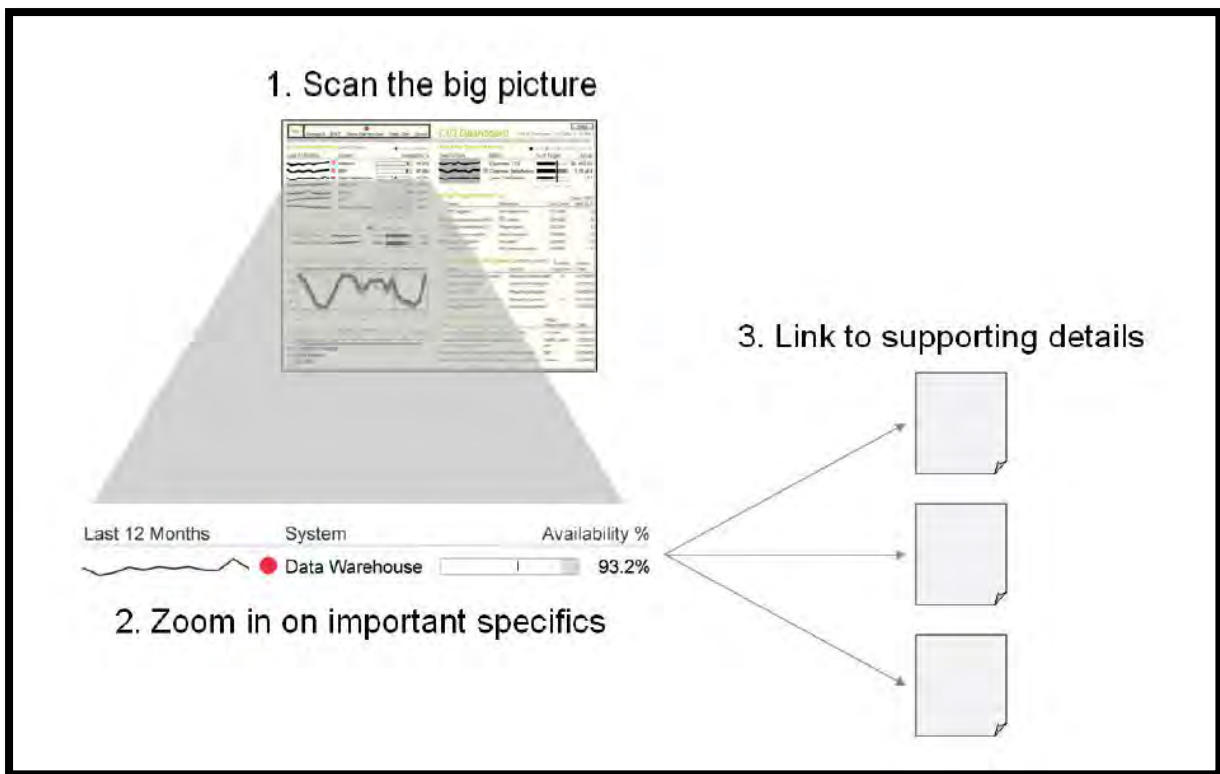


Figure 4.2 – A depiction of the dashboard activities (Few, 2006).

New generation dashboards should (a) align with the organizations processes through providing relevant information (b) be intuitive with easily digestible visuals that communicate information to the users (c) “sound” navigation; (b) and (c) are the most important for the user to make sense or interpret visualized data (Yigitbasioglu & Velcu, 2012). The next section looks at some of the dashboard features that are can be included in a dashboard design.

4.2. DASHBOARD FEATURES

To design a dashboard, the difference between visual and features should be understood. Both features have the potential to amplify cognition and interpretation (Ghazisaeidi et al., 2015).

4.2.1. Visual Features

Visual features enhance information coding and visualization (Yigitbasioglu & Velcu, 2012). They deal with the efficiency and effectiveness of information presentation; if done poorly, the user will become confused thus affecting decision-making. A good balance should be made between the usefulness of information and visual complexity. The design of visual features

should consider the users (cognitive profile, personality background, and analytical skills), the tasks, and level of complexity of the decision environment. In other words, visual features that can accommodate the demands of the users, the tasks and the decision environment are important for designing a dashboard (Ghazisaeidi et al., 2015). The insights gained from the previous chapter (i.e. various data visualization techniques, theory, and design processes) are part of the “visual features” of the dashboard. For instance, cognitive fit theory (Section 3.2.4) states that tables are better for the extraction of specific values and the combination of these values to aid judgement or decision, while graphs are better suited for identifying relationships between values (e.g. ranking, comparing, forecasting, comparing, and pattern recognition). In addition, tables become more valuable when the environment complexity escalates (i.e. specific values are required); graphs offer better decision support for users with low analytical skills (Ghazisaeidi et al., 2015). The dashboard is designed for a specific domain; therefore, the users already have a specific mental model of how things are organized and how changes are tracked. The dashboard will be effective if it fits this internal mental model of the user. An example of a technique used is to give the user the opportunity to draw pictures that can allow them to “externalize” the mental model that will be useful in the dashboard design (Few, 2006).

According to Weggelaar-Jansen et al. (2018), a dashboard normally has three fundamental elements:

- **Heading** – explains the purpose and the content of the dashboard
- **Diagrams** – for visualizing data or metrics
- **Text-based summaries** – short explanations of the information and status of the diagrams; describe key information (e.g. a sentence that includes data points). This provides comprehensive results by informing the user about the possible reasons (causes) and meanings of results; also provides the user with next (possible) actions that can be undertaken.

4.2.2. Functional Features

Functional features describe what the dashboard does. They also support cognitive fit for various types of users through providing various functions that can be used to make changes on the way data is presented (Yigitbasioglu & Velcu, 2012). These features must fit with the purpose (presenting the right information) of the dashboard for accurate decision support. The

purpose may differ and range between knowledge discovery and static reporting. Therefore, the purpose of the dashboard has to be determined to add the appropriate functional features to the design (Ghazisaeidi et al., 2015). Functional features that can be used include:

- **Drill-down capabilities** – are essential for presenting a detailed analysis i.e. for additional information or lower level detail. It has two components: the source (captures the visualization/ chart and the data point that was selected or clicked on) and the destination (presents the relevant information related to the source). This allows the user to return to the original view easily. Two ways of presenting additional information: a **small pop-up window** – allows small sets of additional information to be presented e.g. hovering the mouse on a data point for a small window to “pop-up”; **links** to a separate view or display for more detailed additional information when the user wants make a further exploration.
- **Tabs and pivots** - are links that allow the user to navigate through the dashboard. Tabs (horizontally or vertically) presented with a short title for users to see various views. Pivots are a drop-down list of links that can be selected to navigate to a certain view.
- **Filtering** – global (entire dashboard) or local (specific chart, view, or metric) filtering for sorting/ grouping/ sifting according to certain attributes. Allows the reduction information presented at a given moment.
- **Pruning** – removing irrelevant information for better interpretation of visual representation.
- **Alerts** – for warning users about values that deviate from the norm.
- **Exporting/printing** – to convert information into a different format such as a pdf.
- **Annotation** – to allow users to make comments
- **Saving/tracking** changes – for reuse (future) of personal content settings
- **Redo/undo** changes or actions.
- **Help and user orientation** – to guide the user on how to navigate through the dashboard.
- **Other features include** - drag and drop, zooming, multilingual, expand/ collapse groups, bookmarking, forecasting, scenario analysis etc.

4.3. DESIGNING THE DASHBOARD

Primitive dashboard designs provided very confusing information through a “hodgepodge” display; due to an exclusive focus on metrics thus adding a number of charts and gauges on single page without considering its readability (Juiceanalytics, 2010). Poorly designed dashboards are a detrimental because they can increase the chances of erroneous decisions and difficulties in interpretation (i.e. time-consuming). Well-designed dashboards on the other hand have the potential to “capture the imagination” of the user (i.e. allow the user to explore the data for further insights) (Gunapati, 2011). A balance between information contained in and the visual aspects of dashboards should be made in order to design a dashboard that can support decision-making. This means irrelevant or unnecessary information should be excluded from the dashboard. These well-designed dashboards present crucial information in an appealing manner while reducing the amount of time spent on conducting manual analysis (exploration) (Pestana et al., 2018).

Various authors have suggested a number of design aspects (themes) that can be used to design an effective dashboard and they will be discussed in the following section; all insights gathered will build on (Jespersen, 2017)’s work.

4.3.1. General Design Themes

The dashboard design should follow the right practices (for good design) for an effective communication of data; the users should get answers immediately at a glance without processing the data to understand it (Jespersen, 2017). This section will categorize all design aspects, based on the work of Jespersen (2017), that have been discovered in the literature. Jespersen (2017) provides eleven categories namely; “**target audience**”, “**screen boundaries**”, “**display essential data**”, “**data needs context**”, “**data layout**”, “**choosing the display media**”, “**display media design**”, “**highlighting important information**”, “**colour palette**”, “**make the dashboard attractive**”, “**time and updates**”. The latter (“**time and updates**”) was not found to be relevant in this research. The rest of the categories provide structure (“themes”) for all relevant design aspects discovered from the literature. Thus, forming the foundation of the main artefact (design guidelines) of this research. Each category is outlined in Table 4.1.

It is imperative to note that the categories were merely used as “themes” that provide structure for all dashboard design aspects (features) discovered through this research; therefore,

adaptations on the “meanings” of each category were made to accommodate all relevant dashboard design aspects (features).

Table 4.1 – Design guideline categories (Jespersen, 2017)

<p>TARGET AUDIENCE</p> <p>The users’ needs, which are often different from the designer, should be understood and catered for in a good dashboard design.</p>
<p>SCREEN BOUNDARIES</p> <p>The dashboard should present related information on a single screen without (limited) scrolling/ panning requirements.</p>
<p>DISPLAY ESSENTIAL DATA</p> <p>The dashboard should present essential information only, for analysis purposes (i.e. data trends/ patterns/ aggregation instead of precise figures or numbers).</p>
<p>DATA NEEDS CONTEXT</p> <p>Data needs context in order for the user to understand the meaning of it e.g. is a metric indicating good or bad.</p>
<p>DATA LAYOUT</p> <p>Data should be presented according to importance (i.e. top/ left-hand side for most critical - noteworthy/ newsworthy - data/ information), and association (i.e. side by side).</p>
<p>CHOOSING THE DISPLAY MEDIA</p> <p>The correct (effective/ suitable) media (e.g. text, map, or graph) should be used for displaying data.</p>
<p>DISPLAY MEDIA DESIGN</p> <p>Consistency and standards for icons and labels that are familiar to the user should be applied to convey data to the user effectively.</p>

HIGHLIGHTING IMPORTANT INFORMATION

Information that needs the immediate attention of the user should be highlight to ensure it stands out from the rest.

COLOUR PALETTE

Minimum, appropriate, colours should be used to convey the meaning of data and for the overall design.

MAKE THE DASHBOARD ATTRACTIVE

The dashboard should be simple, neat and clean (i.e. attractive).

TARGET AUDIENCE

The users' needs, which are often different from the designer, should be understood and catered for in a good dashboard design. These are the individuals who will be using the dashboard and their feedback on the design is crucial (Jespersen, 2017). Also, the dashboard needs to be customizable to cater for different users and tasks while displaying relevant information required for making decisions (Hansoti, 2010).

SCREEN BOUNDARIES

The dashboard should present information on a single screen without (limited) scrolling and panning requirements; scrolling through pages makes it difficult for users to view connections between fragmented data (Cheng et al., 2011; Gunapati, 2011; Zheng, 2017). It should provide a complete overview of the situation at a glance of the user. Content should not be hidden because the user will believe it is less important; also, comparisons are harder if the user has to scroll between data displayed. Furthermore, dashboard elements, on a single view or page, should be conceptually and logically related to one another (Staron, 2015). A good approach is to fragment data into multiple dashboard screens to ensure data that is related (belongs together) is not separated. Lastly, the dashboard may also be designed for various screen sizes while also offering the same functionality e.g. desktop, smartphones, and tablets (Jespersen, 2017).

DISPLAY ESSENTIAL DATA

The dashboard should present essential information only, for analysis purposes; i.e. decorative visual components should be avoided (Gunapati, 2011). Only a minimum dataset should be displayed; there should be no precise figures or numbers; calculations should be done for the user to reduce the workload of data processing and analysis. The dashboard content should be limited to ensure that the dashboard display is not cluttered and does not overload or overwhelm the user with information (Malik, 2005). A five-second rule should be followed to ensure the users finds what they are looking for in five seconds or less. In addition, there should only be around 5-9 (7 ± 2) objects on the dashboard to minimize clustering (Jespersen, 2017). This is due to the small number of elements (diagrams, explanations, buttons, text fields) that can be kept in the short-term memory (Staron, 2015).

DATA NEEDS CONTEXT

Data needs context in order for the user to understand the meaning of it e.g. is a metric indicating good or bad. The user will be unable to understand the actions that need to be taken if there is no context provided with the data presented (Jespersen, 2017). For instance, context (e.g. targets) is important for comparisons e.g., “sales revenue for the last quarter totalling \$1,347,384 would be phenomenal for some companies but the sign of impending bankruptcy for others. Only a comparison can reveal the distinction. Compared to a quarterly revenue target of \$1,000,000, you did well, but a target of \$2,000,000 would tell a different story” (Few, 2006).

DATA LAYOUT

Important data should be placed towards the top and left-hand side of the dashboard display; most people read from left to right therefore their eyes are automatically fixed at the top left corner first. Data that needs to be compared should be placed or grouped together (i.e. visual perception principles). The layout can be organized in the following manner; the top shows noteworthy (newsworthy) information, the middle present important information, and the bottom shows general information (Jespersen, 2017). The dashboard screen may have multiple windows (frames) to contain different charts (visualizations) that are independent to each other (Figure 4.3). However, the user should not be overwhelmed with a large number of windows (frames); because each window will call or draw the user’s attention, simultaneously. Therefore, a maximum of six windows is recommended to ensure that the display is effective. Symmetry and proportion should be carefully considered when placing the windows on the

dashboards. Uniform sized windows are recommended to ensure the visualizations are given equal importance unless priority has to be given to a single window (Malik, 2005).

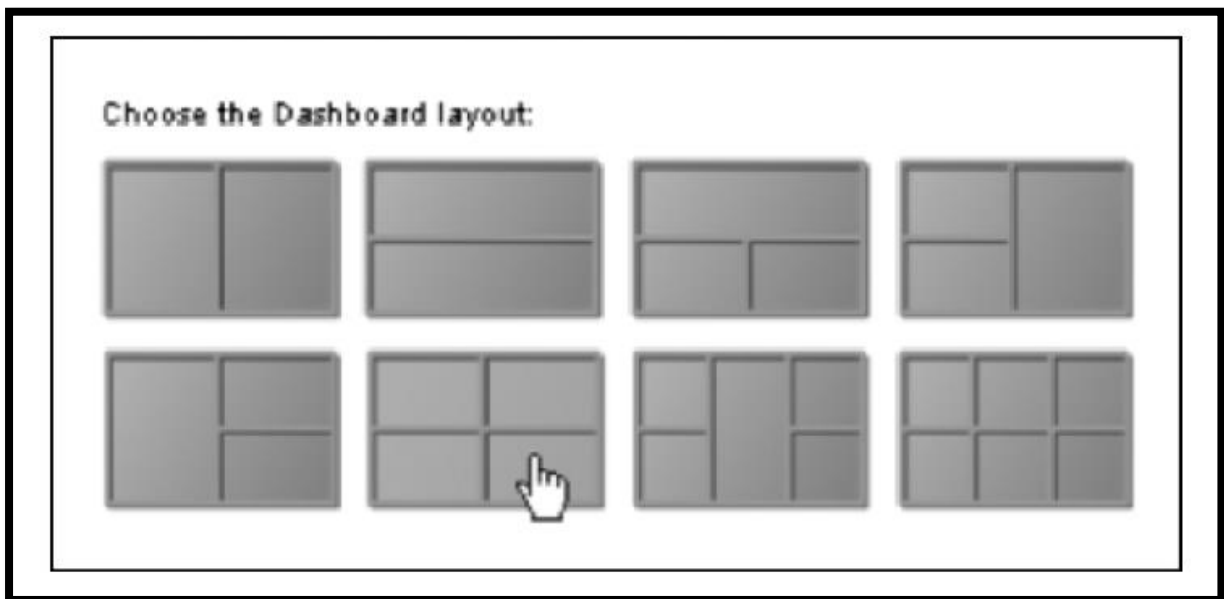


Figure 4.3 – Examples of window layouts (Malik, 2005)

The principles of visual perception form the foundation of a dashboard layout. In other words, these principles (based on Gestalt Laws introduced around 1900s, in Germany) indicate how elements should be placed on the dashboard and which elements are enhancements or pollutants (Pestana et al., 2018). They provide a description of how elements should be arranged in a graphical display. These principles focus on how people interpret the world - in relation to perceptual organization (Chen, 2017a). In other words, they lay a foundation of how visual elements are perceived by the human mind, thus adding value to the dashboard design (Figure 4.3). They are also known as “Gestalt Principles of Visual Perception” and they detail on how to highlight important data from the rest (Jespersen, 2017; Alrehiely et al., 2020).

- **Proximity:** objects (data) that are closer to each other are perceived as related (belong to the same group); space can be used to separate groups.
- **Figure-ground:** less important objects are treated as the background while other objects/ figures are perceived as distinctive.
- **Similarity:** objects that look alike, through size, colour, orientation or shape, are grouped together by the human mind.

- **Enclosure:** objects within a bounding box are perceived by the mind as separate from objects laying outside a bounding box.
- **Closure:** the mind is able to complete semi-finished shapes such as a square with a missing side will not be interpreted as a line.
- **Continuity:** objects that are not connected but aligned to follow one another are perceived as belonging to one group.
- **Symmetry:** objects are perceived as a symmetrical shape around the centre.

Enclosure is stronger than continuity (i.e. bounded box can break continuity); Continuity is stronger than similarity and proximity.

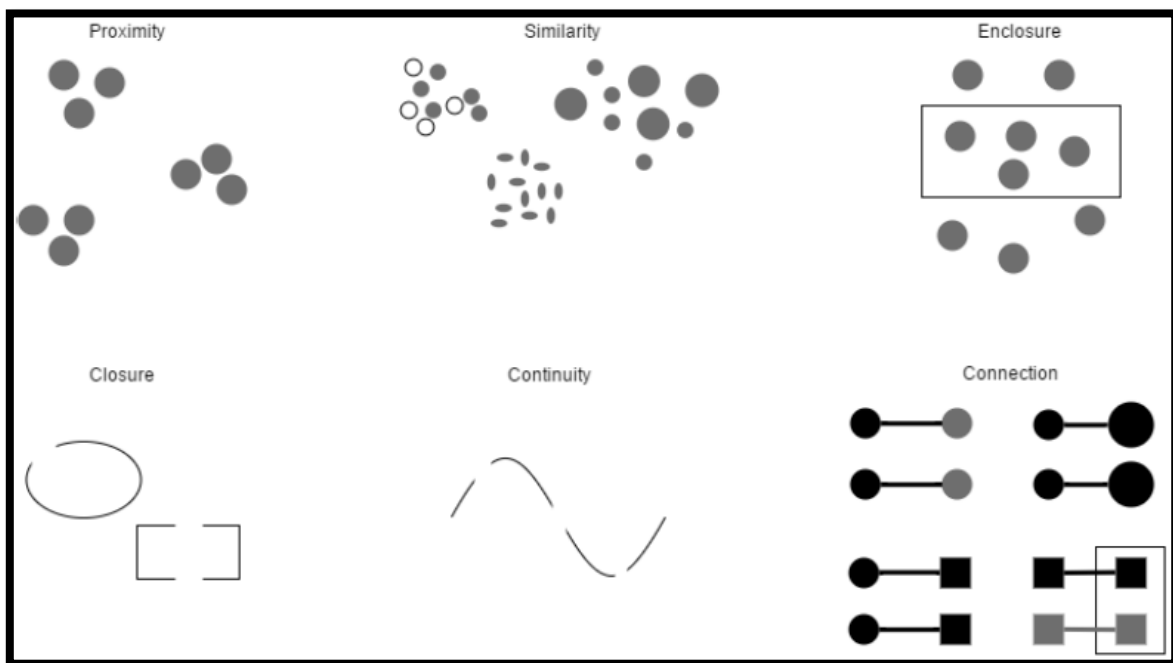


Figure 4.4 – Gestalt Principles of Visual Perception (Jespersen, 2017)

CHOOSING THE DISPLAY MEDIA

Some media are more appropriate than others in terms of the information that is presented e.g. line charts for trends and bar charts for comparisons (Malik, 2005). The correct media should be used for displaying data. The media that is suitable to convey the message to the user in an effective manner should be selected (Jespersen, 2017). e.g. icons – highlighting alerts, tables – for individual value identification, text – for explanation and supplementing graphics, graphs - visual comparisons or trends of data (Gunapati, 2011). There are two scenarios that describe the purpose of the dashboard, thus, determining the selection of visualizations (Janes et al., 2013).

Pull scenario

The dashboard is used to gain specific information when the user needs it. It offers ways to explore, filter, or search data:

- The dashboard should provide the context of the data
- The dashboard should provide meaning of the data i.e. the main message being conveyed.

Push scenario

The dashboard “pushes” information that is important through drawing the user’s attention to unforeseen or unexpected situations (anomalies, problems etc.):

- The dashboard should be used effortlessly; push information to the user without their “active participation”.
- The dashboard should not require the user to interact with the visualizations unless the user enters into the pull scenario.
- Data should be arranged to minimize the time taken to view the dashboard e.g. placing information in the same spot.
- The user’s attention should be diverted to the important information.
- A dashboard (elements) that is visually appealing may build the user’s interest in looking at it.

DISPLAY MEDIA DESIGN

Clutter should be minimized as stated by Tufte (1983) in Section 3.2.1. Standards for icons and labels that are familiar to the user should be selected to convey data to the user effectively. Shadows, 3D effects, gridlines are some of the things that should not be included (avoided) in a display medium. The display medium should have a similar look across all displays for a better user experience (Jespersen, 2017). Consistency in design to ensure easier data comparisons (Cheng et al., 2011).

HIGHLIGHTING IMPORTANT INFORMATION

Information that needs the immediate attention of the user should be highlighted to ensure it stands out from the rest. This should be done sparingly to ensure it is not overused thus losing its purpose (Jespersen, 2017). Pre-attentive processing is a technique that can be used to allow user to process information without paying attention to it (Janes et al., 2013). Pre-attentive visual processing creates visual presentation in the sensory memory. Viewers perceive pre-

attentive attributes instantaneously; intervention of consciousness is not required (Chen, 2017b). For instance, Figure 4.5 shows evidence that counting the number of “3’s” in “(b)” is easier than in “(a)”.

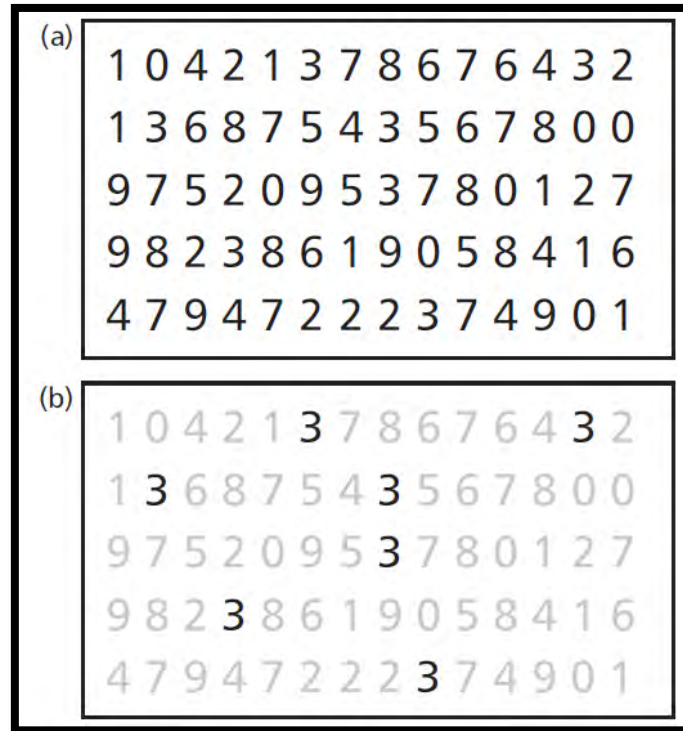


Figure 4.5 – “How many ‘3s’...?” (Janes et al., 2013)

Using more than one pre-processing properties (e.g. colour, and/ or shape) to capture the users attention aggravates the situation further (i.e. makes it even more difficult) (Figure 4.6).

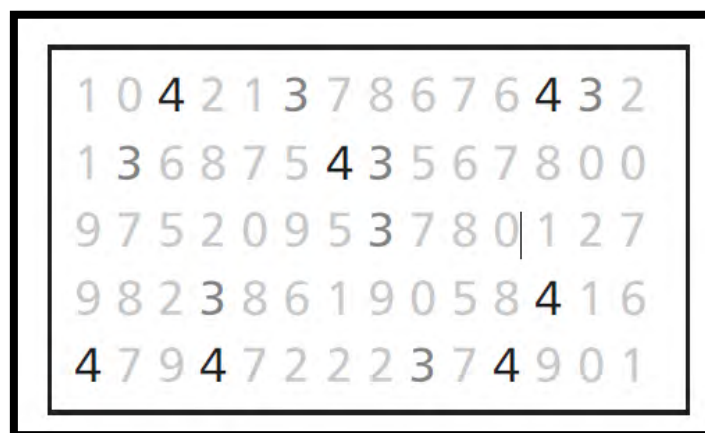


Figure 4.6 – Counting the number of “3s” and “4s” requires more time for the brain to process (Janes et al., 2013)

COLOUR PALETTE

Colour should be used to clarify content – if users do not respond well to traffic light colour coding (red = bad, orange = mediocre, and green = good performance) because it evokes a feeling of shame inside the users (i.e. a red indicator flashing for too long), neutral colour coding should be opted for (Weggelaar-Jansen et al., 2018). Minimum use of colours – colours should enhance diagrams and highlight important information (Staron, 2015). Only a few colours (2-3 colours and gradients of the same colour) should be included in the design. Contrasting colours are useful – the user may perceive data that has similar colours is different from data placed on other parts of the screen (Jespersen, 2017). Due to individual differences, the alternatives (e.g. colour) should be given to the users who prefer not to use “defaults”; while still drawing the attention to the important information. Some of the rules of using colours are summarized in Figure 4.7.

Rule	Description of rules
Rule 1	If you want different objects of the same color in a table or graph to look the same, make sure that the background the color that surrounds them is consistent.
Rule 2	If you want objects in a table or graph to be easily seen, use a background color that contrasts sufficiently with the object.
Rule 3	Use color only when needed to serve a specific communication goal.
Rule 4	Use different colors only when they correspond to differences of meaning in the data.
Rule 5	Use soft, natural colors to display most information and bright and/or dark colors to highlight information that requires greater attention.
Rule 6	When using color to encode a sequential range of quantitative values, stick with a single hue (or a small set of closely related hues) and vary intensity from pale colors for lower values to increasingly darker and brighter colors for higher values.
Rule 7	Non-data components of tables and graphs should be displayed just visibly enough to perform their role, but no more so, for excessive salience could cause them to distract attention from the data.
Rule 8	To guarantee that most people who are color blind can distinguish groups of data that are color coded, avoid using a combination of red and green in the same display.
Rule 9	Avoid using visual effects in graphs.

Figure 4.7 – Rules of using colour (Pestana et al., 2020)

MAKE THE DASHBOARD ATTRACTIVE

The dashboard should be neat and clean through good theme choices such as material or flat designs, high-resolution images and text, colour choice, font type and content layout (Jespersen, 2017).

4.4. CONCLUSION

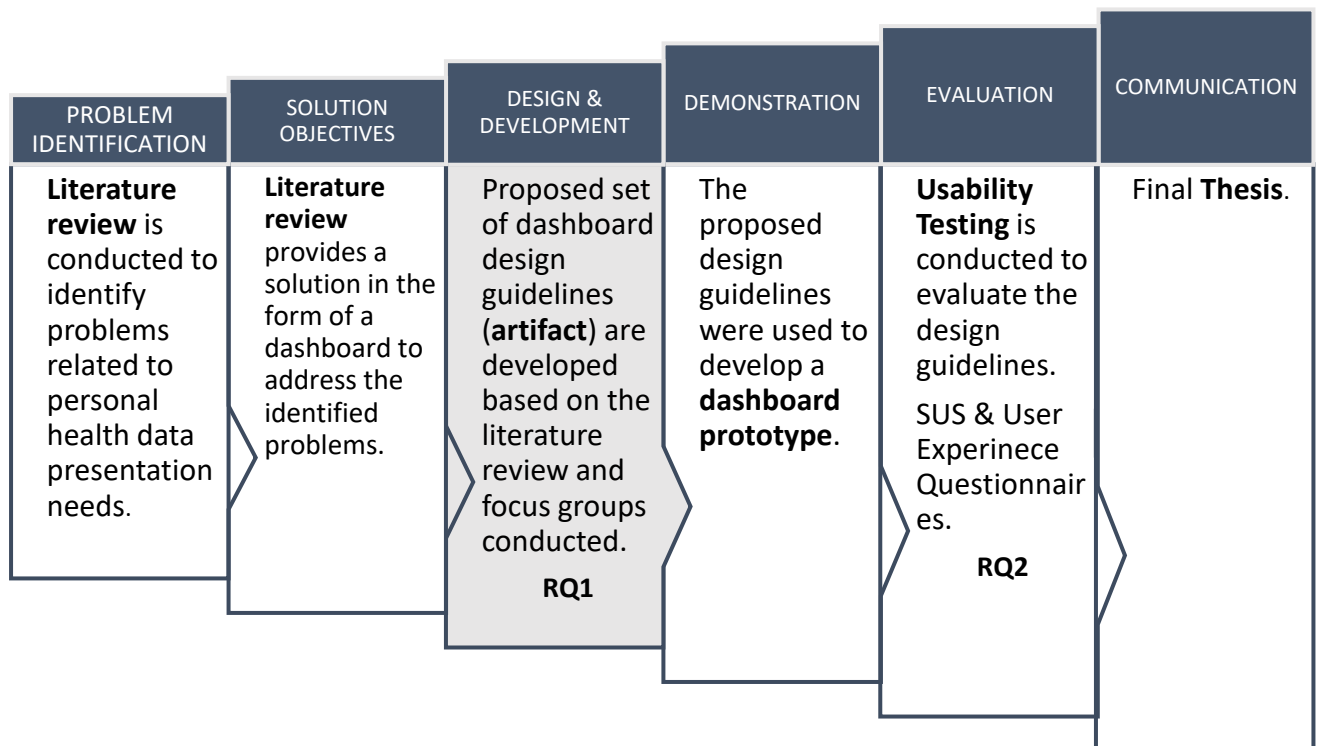
This chapter looked at various aspects (i.e. visual and functional) that need to be considered for presenting information to the user in a form of a dashboard; i.e. designing a “good” (effective) dashboard. A preliminary set of design aspects (Table 4.2) resulted from this chapter in order to provide insights about what forms the foundation of a dashboard (design). Categories by Jespersen (2017) provided a structure for all the aspects that were discovered about dashboard designs in general. The proceeding chapter aims at understanding dashboards in the health care domain. It uncovers design aspects that are utilized in clinical and personal health dashboards. Therefore, the next chapter aims at uncovering aspects (insights) that are more specific to addressing health-data-presentation needs.

Table 4.2 – Design aspects that were discovered

Categories	Design Aspects
Target audience	<ul style="list-style-type: none"> • Personalization • Customizability
Screen Boundaries	<ul style="list-style-type: none"> • Related data per view/ page • Limited scrolling and panning • Single view/ page
Display Essential Data	<ul style="list-style-type: none"> • 5-9 (7/+2) data elements • Essential information only • Summarized/ overview data • Minimize clustering
Data Needs Context	<ul style="list-style-type: none"> • Data context
Layout	<ul style="list-style-type: none"> • Important data on the Top (left) to right; Comparison groups • Multiple windows; Symmetry and proportion • Principles of visual perception • Navigation
Choosing the Display Media	<ul style="list-style-type: none"> • Appropriate data medium e.g. icons, tables, text, graphs

	<ul style="list-style-type: none"> • Pull/ push data scenario
Display Media Design	<ul style="list-style-type: none"> • Domain specific media (i.e. icons, labels); Uniform medium design • Design Consistency
Highlighting Important Information	<ul style="list-style-type: none"> • Highlighting • Benchmarking • Pre-attentive processing • Reminders (messages)
Colour Palette	<ul style="list-style-type: none"> • Colour for content clarity; Contrasting colours • Neutral colour coding • Minimum use of colours • Same colour gradients/ 2-3 colours • Rules of colour
Make the dashboard attractive	<ul style="list-style-type: none"> ▪ Neat and clean dashboard design

CHAPTER 5:
HEALTH DASHBOARDS



In this chapter, the importance of dashboards in the health care domain is detailed. Furthermore, the dashboard design aspects that are relevant to the healthcare domain are uncovered. This chapter aims at finding domain specific dashboard design aspects that allow users to be able to interpret health data easily for making health-based decisions. The chapter is divided into two sections: 1) clinical dashboards that uncovers dashboard design aspects that are being used by health professionals; 2) personal health dashboards – this section provides dashboard design aspects that are relevant/ suitable for users who want to understand and monitor their personal health. The latter is the focal point of this research in order for assessing the degree to which the design guidelines can be tailored for users.

5.1. OVERVIEW

The main challenge of the large amount of data generated daily is finding ways to make it accessible and intelligible by presenting it as information. As stated in Chapter 4, dashboards provide a visual and graphical presentation of information (Toasa et al., 2018). A health dashboard is a tool that provides a cross-sectional view of various metrics such as patient's status and safety, healthcare delivery and performance metrics, and overall patient satisfaction or outcomes. These dashboards are created using commercial or custom-built tools (Badgeley et al., 2016). Integrating health information on a single screen supports quick decision-making.

Anticipated and unanticipated patterns are recognized from the information, thus, timely and comprehensible evaluation allows timely actions to be taken. However, the dashboard has to provide quality information to ensure high quality decisions (Rouhani et al., 2018).

Patient safety and care is affected by the interrelationship between clinical cognitive workload and workflow. Medical errors are mainly caused by cognitive overload - contributes to about 80% of the errors made by the dashboard user, and inefficient and ineffective collaboration and communication between patient care teams thus adversely affecting clinical workflow. The quality of healthcare is impacted by “cognitive strain and irregular thinking patterns” of health data interpreters (i.e. the users) who are required to analyse large volumes of complex textual and numeric data (Faiola et al., 2015). Access to accurate and intuitive health related information (e.g. medical condition) is important for users (i.e. health professionals or ordinary users/ patients) to conduct their tasks or understand their health. However, due to information scattering (silos) and overload - the result of the large amounts of data available - the users are forced to spend a lot of their time analysing health information required and may miss important information (Lee et al., 2017).

The use of computer-supported graphics to represent large amounts of health data enhances the cognitive process (reduces cognitive load), decreases health related errors (e.g. clinical errors, misinterpretations), speed of information assimilation, recognition of patterns etc. Thus, healthcare individuals need useful data presentation (i.e. in the form of a dashboard) to support these functions (abilities). Health dashboards can provide a solution that resolves problems associated with interpreting health data; through organizing and visualizing health data (e.g. temporally/spatially), enhancing situation-awareness and contextual diagnosis (e.g. comparing data points overtime), improving collaboration and knowledge sharing (e.g. incorporating asynchronous and synchronous technologies), and ensuring ubiquitously available visualizations (Faiola et al., 2015). However, it is important to note that the dashboard is not designed to replace health information systems (i.e. data repositories); it should be interoperable with existing health information systems. It is designed to capture and present relevant and important information from these systems (Lee et al., 2017).

There is limited literature on the design of health dashboards. However, this research makes an effort to synthesize everything that was discovered about health dashboards. This chapter

will split health dashboards into two categories: a) clinical dashboards – mainly used by healthcare providers, and b) personal health dashboards – often used by any “health conscious” individual.

5.2. CLINICAL DASHBOARD

The healthcare providers work environment is complicated and it involves switching between a number of tasks and patients. The healthcare providers are faced with the challenge of maintaining “situation-awareness” (i.e. knowing all relevant information across distributed systems and understanding what is going on around them). For instance, a nurse realising that an order for medication is required thus raising the need to act on it. If the health provider experiences a challenge with monitoring the patient’s state continuously, situation-awareness will be lost. Visualizing health information can support clinicians with detecting, interpreting, understanding, and evaluating health data thus allowing real-time decision making (Franklin et al., 2017).

A clinical dashboard is a tool set that presents data in a usable, concise and visual format on a visual display; in a timely and accurate manner for supporting decision-making. Clinical dashboards are required to organize and present health data efficiently; addressing specific information needs i.e. there is no “one-size-fits-all” solution (Swartz et al., 2014). Healthcare professionals use these dashboards for multiple purposes such as performance metrics/ benchmarking, disease surveillance, healthcare quality assurance, medical resource management, patient follow-ups etc.

Healthcare providers require access to historical information (e.g. previous medical history, past visits) in an appropriate format and timely manner with the least amount of cognitive effort. Clinical facilities have systems that are integrated to provide electronic medical information or medical services across departments (Sloane et al., 2006; Daley et al., 2013; Swartz et al., 2014). The dashboard is designed to allow users (at all organizational levels; novice and expert users) of the electronic medical systems to interact and interpret information that is integrated by these systems. The dashboard turns that information into a more easily usable and interpretable formats that support inform decisions (Sloane et al., 2006). Thus, important information for completing tasks is presented to the healthcare providers for making

decisions (Daley et al., 2013). Figure 5.1 is an example of a health dashboard that integrates all patient data to provide the healthcare provider a holistic view of each patient.

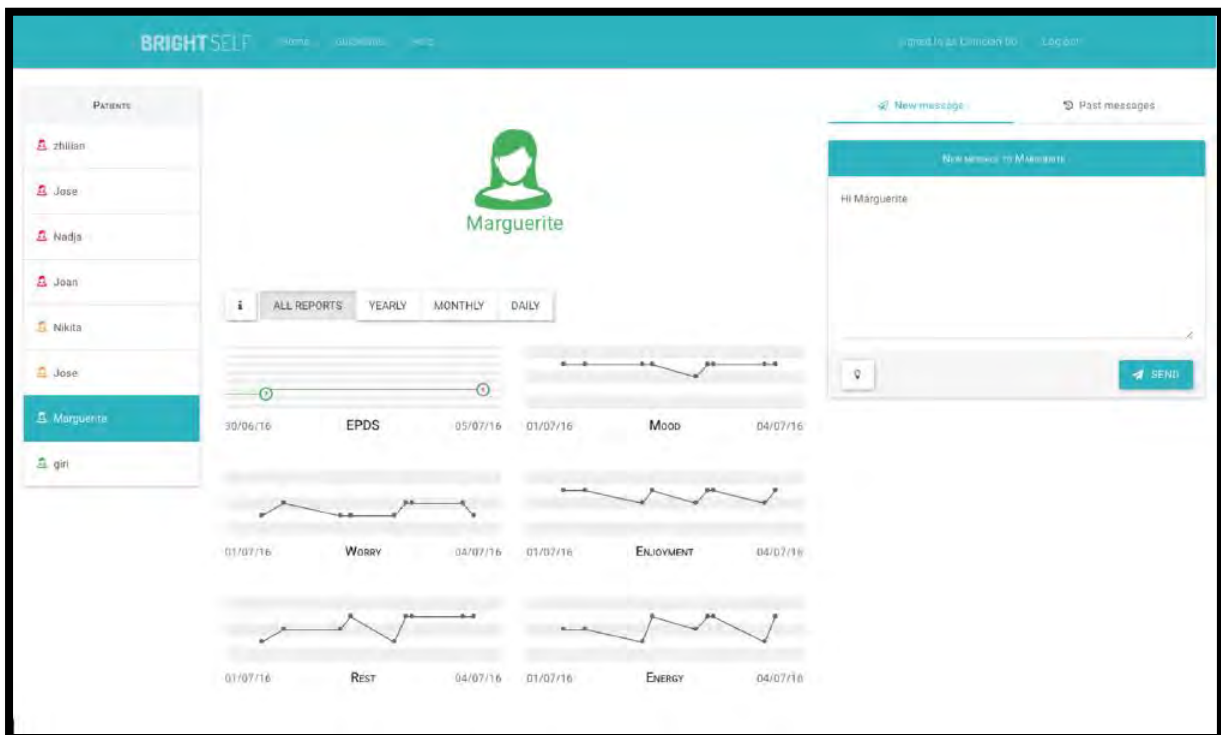


Figure 5.1 – An example of a dashboard used to keep track of various patients (Doherty et al., 2020).

5.2.1. Clinical Dashboard Design

Although there is limited literature, this section tries to put together all that could be found about the way dashboard are designed for healthcare providers.

INFORMATION SEEKING APPROACH

Similar to Chapter 4 (Figure 4.2), an “information seeking approach” is fundamental to the design of clinical dashboards. This approach allows healthcare providers to probe for details from a holistic view of health information (De Croon et al., 2015; Concannon et al., 2019). To reiterate, this approach does the following (Figure 5.2):

1. Provides an overview of information (e.g. patients or patient summary, or at-a-glance snapshot),
2. Allows zooming and filtering (e.g. filtering patients by criteria), and

- Provides details on demand (drill down capabilities for additional information e.g. picture, name, age, gender, condition, degree, main GP etc.)



Figure 5.2 – An information seeking approach (De Croon et al., 2015).

Referring to Figure 5.2, part “A”, the healthcare professional selects an area on the parallel axes to filter the data. Part “B” presents the health data of filtered or selected patients. Part “C” provides details on demand by listing the filtered patients (De Croon et al., 2015). Drill down functionality in Figure 5.3 provides users with the ability to get more information on demand; a window containing additional information pops-up when users hover or select values (Swartz et al., 2014; Pollack & Pratt, 2020).

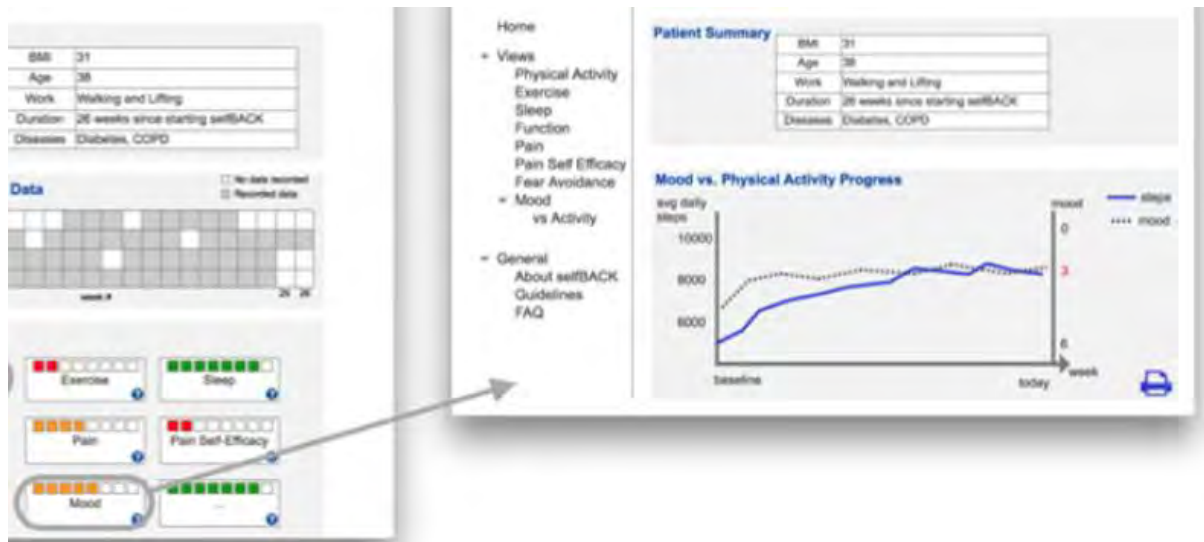


Figure 5.3 – An example of a pop-up view when the user clicks on the progressive bar for additional information (Bach et al., 2019).

DATA PANELS (WINDOWS OR FRAMES)

Similar to Chapter 4 (Figure 4.4), “data panels” are used to support cognitive tasks by organizing most-requested patient information in “windows” (Figure 5.4 & Figure 5.5). Similar data/ information can be placed side by side, within the data panels, for comparisons (Figure 5.6), with minimal data ink (Swartz et al., 2014; Mattingly et al., 2015; Gustafson et al., 2018; Bach et al., 2019).

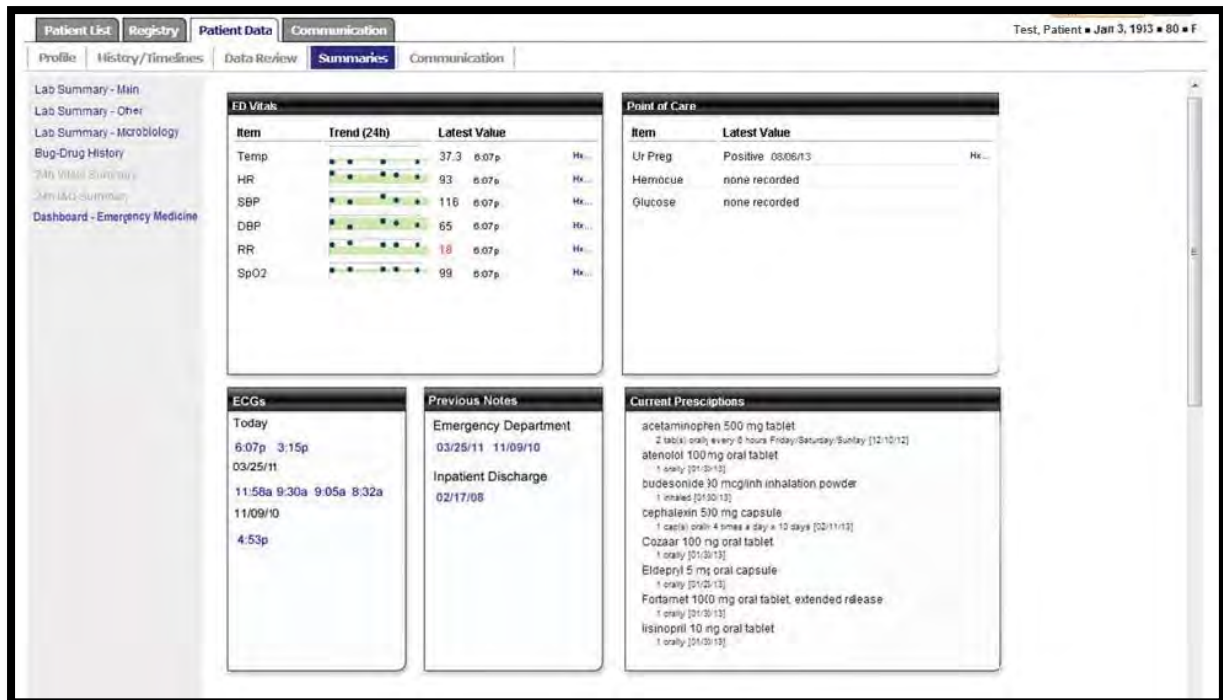


Figure 5.4 – Data panels have been used to group/ organize information into “summary tiles” (Swartz et al., 2014).

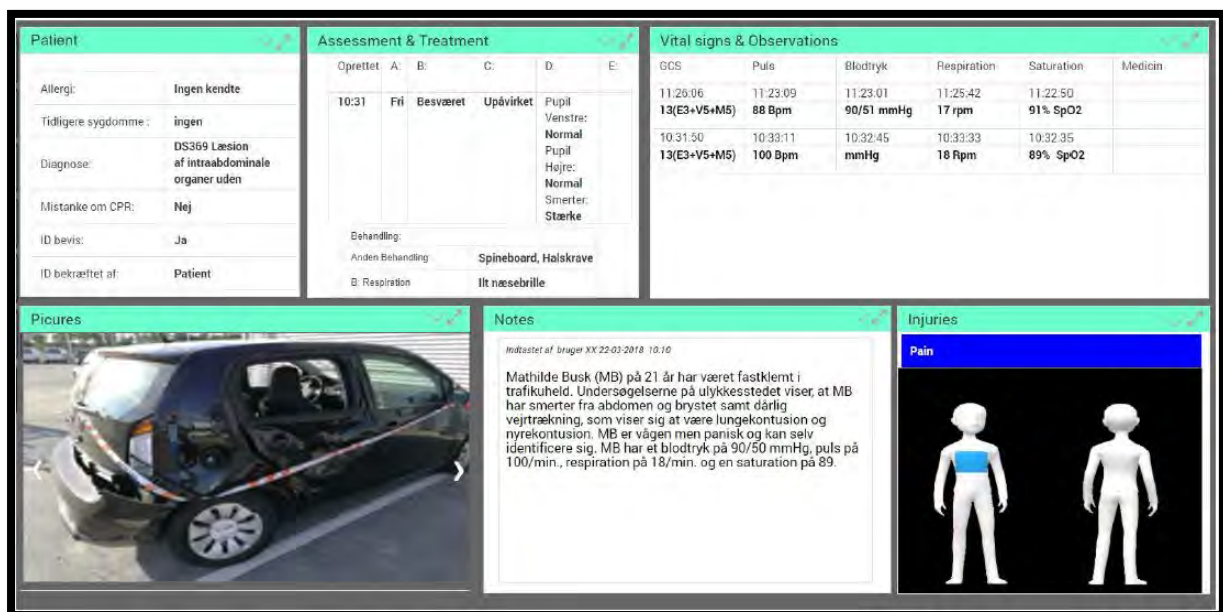


Figure 5.5 – Grouped data into six data panels (Gustafson et al., 2018).

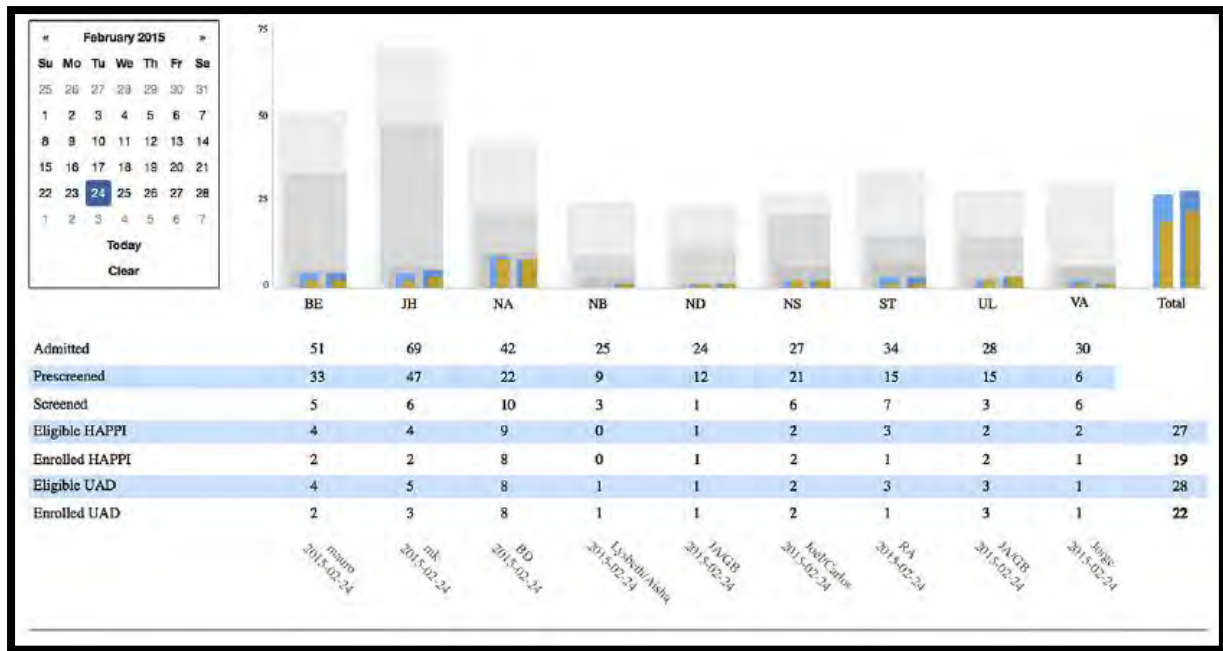


Figure 5.6 – Nine hospitals have been place side by side for comparing daily patient enrolment (Mattingly et al., 2015).

VISUALIZATIONS

Gauges are often used in clinical dashboards (Figure 5.7). These gauges are used for representing numeric values. Other visualizations such as graphs/charts are used to show value trends and comparisons, and tables are used for specific and detailed information. Dynamic designs allow gauges and charts. graphs to be changed or updated based on information filtering (Sloane et al., 2006).

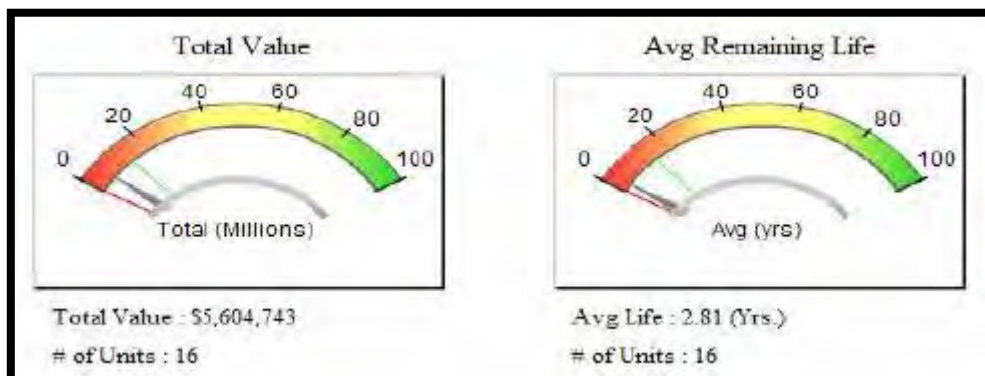


Figure 5.7 – Gauge example (Sloane et al., 2006).

COLOUR AND BENCHMARKING

Looking at Figure 5.7 and Figure 5.8, a colour-coded system has been utilized. A relatively-easily understood colour-coded system (e.g. traffic light system - ‘red, amber, green’ (RAG) colours) is used for metrics (values). Blue/amber/aqua are used for values that are equal to the median (threshold) - indicates an action that may be required soon; green for normal values; and red for abnormal values (breached threshold) (Pemberton et al., 2014; Chandraharan & Arulkumaran, 2016; Vo et al., 2019). This colour-coded system allows abnormal (unforeseen sub-optimal) values to be detected early (Raban et al., 2015; Bach et al., 2019). Colour is also used to indicate to user that a threshold/ benchmark/ “average” (“outlier detection”) has been exceeded (e.g. a horizontal or vertical line that indicates a different state when it has been crossed) (Figure 5.9) (Franklin et al., 2017).

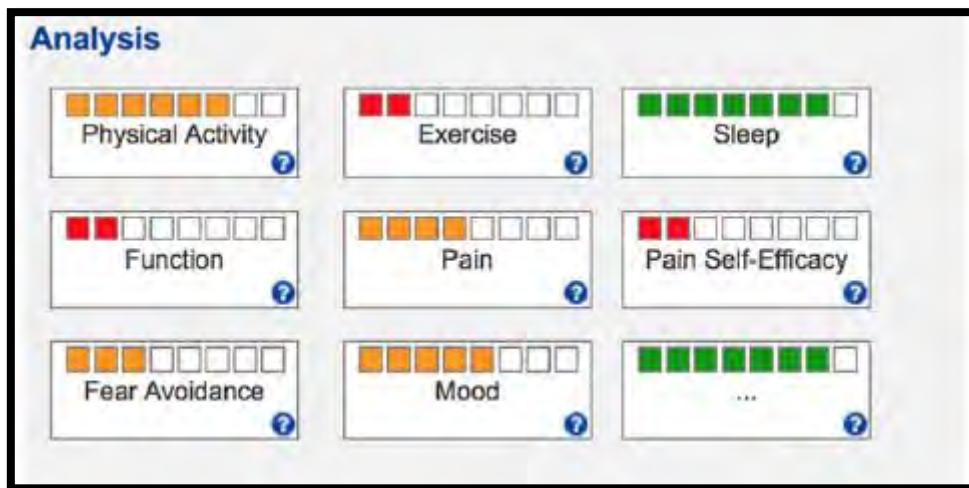


Figure 5.8 - An example that combines the use of a colour-coded system (traffic-light system), and data panels that can be clicked on for further information (information seeking approach) (Bach et al., 2019).



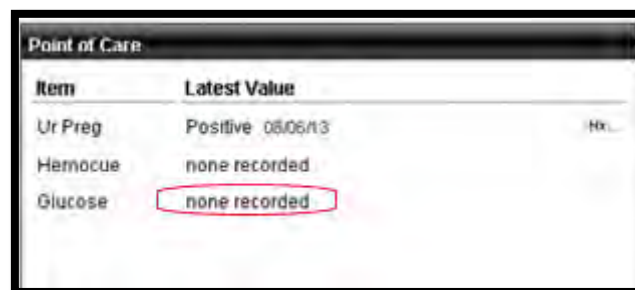
Figure 5.9 - An example that shows the use of a colour coded system including a vertical grey line as a benchmark (“lab average”) (Horback et al., 2021).

NOTIFICATIONS (REMINDERS)

Computerized reminders are also used by healthcare providers to help improve preventive services such as prompting the healthcare providers to click on a fast link to a required action or management tools - when a patient meets a certain condition (criteria) based on the colour-coded system. A reminder message window pops-up to alert the healthcare professional about a patient who has met a specified condition (i.e. often, a critical condition). This brings the healthcare provider’s attention to an individual patient who requires it (McMenamin et al., 2011; Rouhani et al., 2018).

OTHER CLINICAL DASHBOARD DESIGN FEATURES INCLUDE:

- **Data Context** - messages (e.g. “none recorded” or “data is unavailable”) shown when results are unavailable (Figure 5.10) (Swartz et al., 2014).
- **Customizability** to hide/ show certain features or information. This allows certain features/ information of interest to be prioritized (personalization), or the default layout and/ or visualizations to be changed to fit the user’s dynamic needs (Mattingly et al., 2015).
- **Navigation cluster** (Figure 5.11) for moving from one view to another (Gustafson et al., 2018; Bach et al., 2019).



Item	Latest Value
Ur Preg	Positive 08/06/13
Hemocue	none recorded
Glucose	none recorded

Figure 5.10 – Data unavailability messages (Swartz et al., 2014).

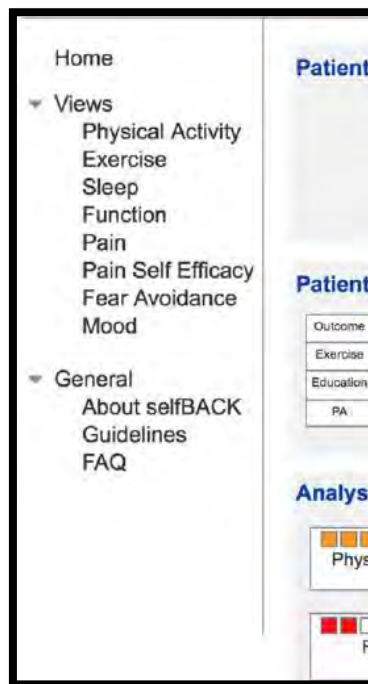


Figure 5.11 - An example of a navigation cluster (Bach et al., 2019).

5.3. PERSONAL HEALTH DASHBOARDS

Literature focuses on clinical dashboards; however, there is a paucity of information around the design of dashboards for “health-conscious” individuals. This research aims at contributing to this knowledge gap, by synthesizing all insights that could be found during the examination of the available literature.

Personal health dashboards are similar to clinical dashboards; however, they are specifically designed for ordinary individuals (non-professionals) instead of healthcare providers. They encourage (motivate) individuals to maintain their well-being (e.g. increased physical activity, better eating behaviours, and emotional self-control); thus improving health statuses and clinical outcomes (Zide, 2016; Cajamarca et al., 2020).

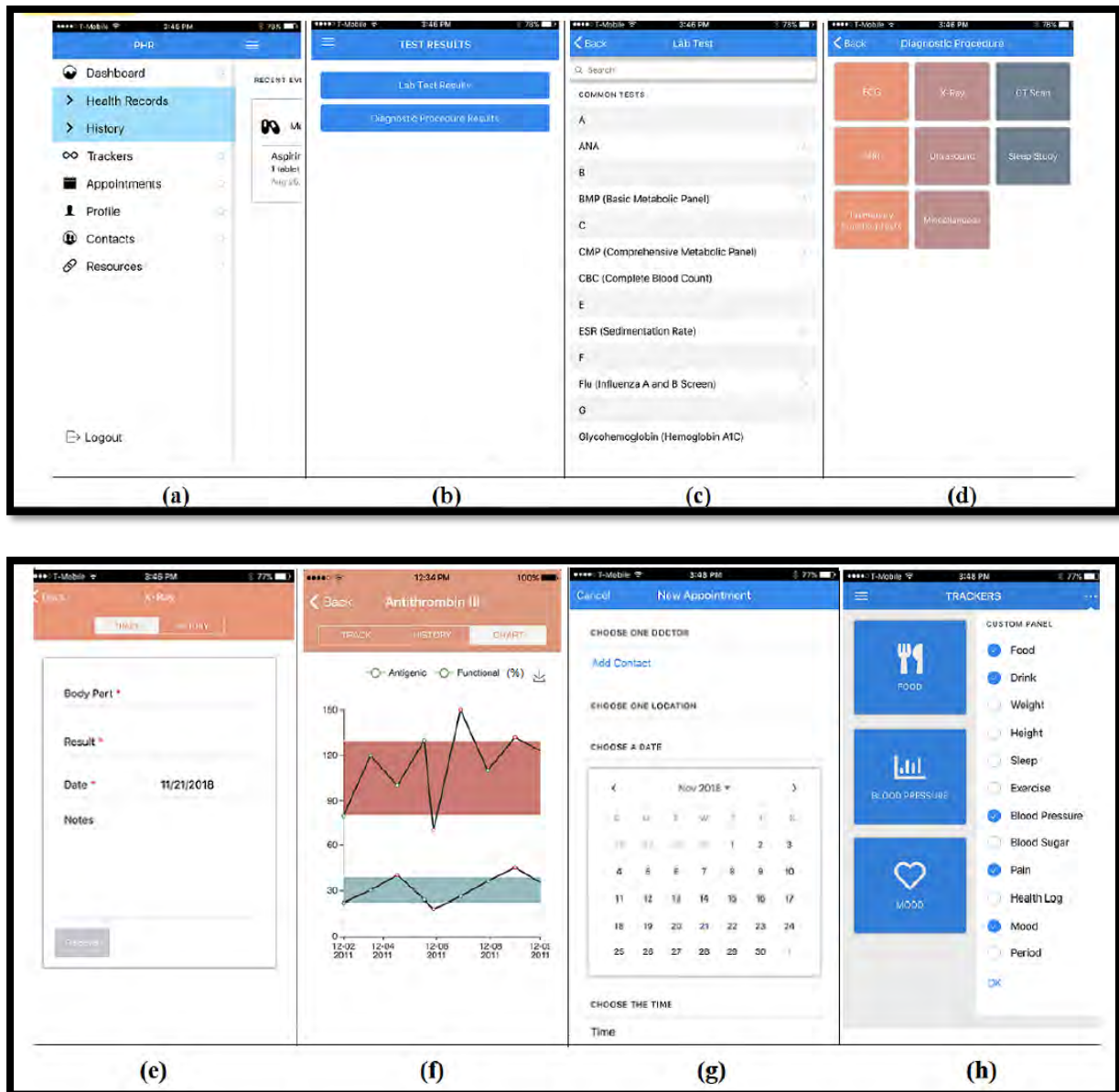


Figure 5.12 – An example of a personal health dashboard (Zhou et al., 2019).

Figure 5.12 shows various screens/ pages/ views of a mobile personal health dashboard. The design has the following features (elements): “(a)” navigation, “(b)” test result options, “(c)” lab tests, “(d)” diagnostic procedure options (buttons), “(e)” results form, “(f)” Graphed test results, “(g)” Doctor’s appointment page, “(h)” customizing page. The dashboard includes various trackers: sleep, food, height, drink , weight, and exercise (Zhou et al., 2019).

5.3.1. Personal health dashboard design

Not much literature could be found on the design of personal health dashboards. This section summarizes design aspects (features) that were identified from the literature.

Visvalingam et al. (2018) suggests factors that contribute to motivated users: customizability (e.g. display colours, font style/sizes), personalization (e.g. which features should be shown on a daily basis), accessibility (e.g. menus and toolbars for navigation, familiar icons), “complex yet comprehensible graphs”, alerts and proactive support (i.e. necessary reminders), and trust & privacy (i.e. truthful information). This is quite similar to what **Chapter 4** indicated and what clinical dashboards offer; however, these dashboards are tailored for ordinary users.

INFORMATION SEEKING APPROACH

Jin & Li (2019) split the dashboard into three zones (Figure 5.13): 1) visualization zone – charts/ graphs, 2) description zone – simple description, 3) function zone – interaction/ filtering (e.g. for selecting data to view). Similar to clinical dashboards (information seeking approach), personal health dashboards provide an overview – vital signs, and critical observations and motivational information (goal progress and action plans for important disease management issues). Then allows the user to drill down to specific historical data. In other words: overview first, zoom and filter, and details-on-demand (Andry et al., 2009; Wågbø, 2014; Jin & Li, 2019).



Figure 5.13 – A dashboard is split into three zones (Jin & Li, 2019).

VISUALIZATIONS

Graphs are used to present observations (health data); however, it is not a simple task. There are a number of principles that need to be taken into account when using graphs for this purpose (Chapter 3) (Andry et al., 2009): data should be given importance over the rest of the graph, clutter should be reduced, overlapping lines and symbols should be easily recognized or optional. The visualizations (e.g. graphs) can be placed side-by-side to allow viewers to make comparisons (e.g. blood glucose chart vs diet chart) (Colley et al., 2016; Andry et al., 2009; Jin & Li, 2019). On the visualization, colour (e.g. green -> yellow -> orange -> red) is used to indicate values that are within an acceptable value range; with thresholds to mark highest and lowest points on the chart (Andry et al., 2009; Colley et al., 2016; Giordanengo et al., 2019; Jin & Li, 2019).

OTHER PERSONAL HEALTH DASHBOARD DESIGN FEATURES INCLUDE:

- **Reminder notifications** (e.g. a doctor's appointment) to alert users about upcoming events or critical conditions (Visvalingam et al., 2018; Theis, 2019).
- **Log section** – for entering/ updating data (e.g. blood pressure, blood glucose levels) captured using self-monitoring devices (Andry et al., 2009).
- **Extendibility** (i.e. customization) for to adding more features that allow users to view more health information (e.g. allowing users to select up to 5 data parameters per view) (Colley et al., 2016).

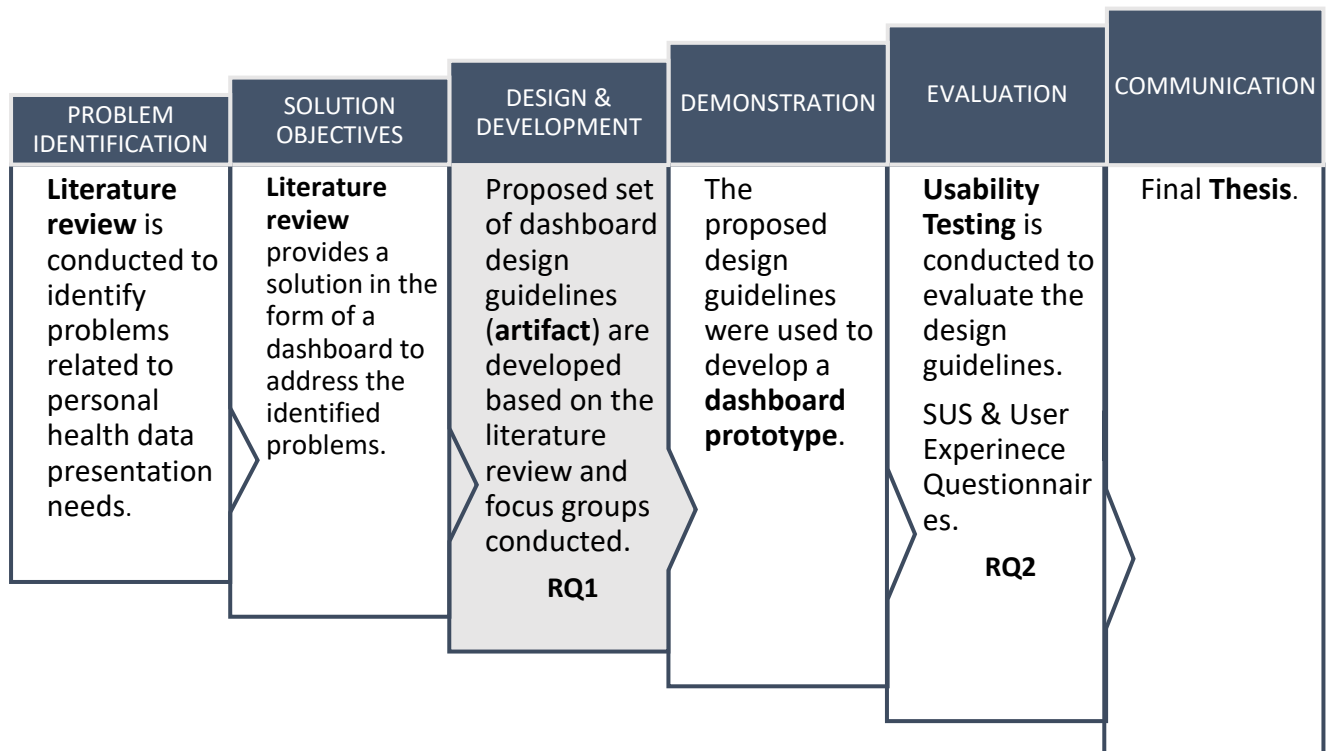
5.4. CONCLUSION

Although there is limited literature on health dashboards, this chapter attempted to provide details on health (i.e. clinical and personal health) dashboards. The dashboard design aspects (Table 5.1) that are relevant to the healthcare domain are uncovered such as suitable colours (traffic light colour coding), and an information seeking approach used to present health data etc. The next chapter will look at focus groups. The focus groups aim at assessing the level of alignment between what was found in the literature (visualization and dashboards) and what an ideal/ prospective user needs from a dashboard. In other words, the proceeding chapter will uncover insights that were missed from the literature, thus, strengthening information that has been learned this far about designing dashboards.

Table 5.1 – Design aspects that were discovered.

Categories	Design Aspects
Target audience	<ul style="list-style-type: none"> • Customizability
Data Needs Context	<ul style="list-style-type: none"> • Messages e.g. “data unavailable”
Layout	<ul style="list-style-type: none"> • Data panels (“summary tiles”) • Overview; Zooming/ Filtering; Details on demand • Principles of visual perception • Navigation
Choosing the Display Media	<ul style="list-style-type: none"> • Appropriate data medium e.g. icons, tables, text, graphs • Downloadable reports
Highlighting Important Information	<ul style="list-style-type: none"> • Benchmarking • Reminders (messages)
Colour Palette	<ul style="list-style-type: none"> • Colour-coded system (traffic light system)

CHAPTER 6:
FOCUS GROUPS



This chapter motivates and outlines how focus groups were conducted in order to discover insights about dashboard design aspects that are relevant to a typical (prospective) user. The focus group discussions allow the literature to be scrutinized in terms of the relevance of discovered dashboard design aspects to a typical user. Furthermore, the focus group discussions assist in uncovering design aspects that were missed or not found in literature.

6.1. RATIONALE FOR FOCUS GROUPS

Focus group is a method that is used in the information systems field to inform the design and/or refinement of artifacts (Tremblay et al., 2010). A focus group is described as moderated, structured in-depth interviews (discussions) on a specific (“focused”) topic with purposely-selected participants who do not necessarily represent the larger population sample. It gathers data (i.e. features that people value and the reasons) about a topic through interactions between participants in synchronous meetings where participants are at the same place and time (Rabiee, 2004; Gibson & Arnott, 2007; Goodman et al., 2012).

For this research, the focus groups are conducted as a more economical manner of data collection because they generate large amounts of information within a, relatively, short period of time (Rabiee, 2004; Goodman et al., 2012; Brandtner et al., 2015). Focus groups offer

invaluable information due to the degree of diversity and consensus within the group (Morgan, 1996). The type of data generated from focus groups is richer and deeper than one-to-one interviews due to group dynamics and the level of social interactions that take place within that session (Rabiee, 2004). This is due to group discussions providing a rich data set that allows this research to draw conclusions about similarities and contrasts in opinions or perspectives between the participants (Gibson & Arnott, 2007).

There are four types of focus groups: feature prioritization, competitive analysis, trend explanation and exploratory focus group - all of which look at designing and refining an artifact (Tremblay et al., 2010; Goodman et al., 2012). Furthermore, focus groups can either be for observing participant's interactions or open-ended, semi-structured, interviews (Gibson & Arnott, 2007). This research conducts open-ended, semi-structured interviews within exploratory focus groups. Predefined set of open-ended questions are used to guide the thoughts and ideas shared by the participants (Brandtner et al., 2015). The goal is to conduct spontaneous questions (i.e. the main aim of focus groups) to encourage participants to share novel ideas, comments, feelings or issues that would, otherwise, have not been thought of (anticipated) (Tremblay et al., 2010; Brandtner et al., 2015). Based on recommendations from other researchers, participants are put together to gain an honest, spontaneous expression of numerous opinions (Rabiee, 2004).

There is limited research on dashboard designs (and graphically presenting information), thus, when little is known about a topic (i.e. in the case of this research - personal health dashboards), focus groups are a powerful tool that can allow a “phenomenon” be explored a bit further (Morgan, 1996; Rabiee, 2004; Gibson & Arnott, 2007; Tremblay et al., 2010). This research finds value in the back and forth discussions between participants because, compared to individual interviews, focus groups do not require the interviewer to make assumptions or aggregate individualistic views to try make sense of the differences between individuals' opinions (Morgan, 1996). The technique allows information to be collected within the group while also highlighting the differences in perspectives between individuals across groups. This research aimed at running more than one focus group session because multiple focus groups provide the interviewer with a wide range of views across multiple groups that he/ she can examine to better understand the topic(s) at hand (Rabiee, 2004; Tremblay et al., 2010).

Focus groups can be ran until a pattern is detected or when information produced by subsequent groups becomes monotonous (repetitive). The manageable size of the focus groups is regarded

as one with about six to ten participants to gather a fair amount of valuable perspective/ opinions/ information. Not more than seven participants are recommended for discussing complex problems or issues. This research utilizes four participants per session which is recommended for less complex topics (i.e. where non-technical expertise is required) (Rabiee, 2004; Brandtner et al., 2015). Smaller groups are more likely to produce better results. The benefits of using the method can be summarized as follows:

1. It uncovers opinions or ideas that are usually covert in individual interviews.
2. Provides access to a large pool of both qualitative and quantitative information.
3. The interviewer has access to prospective users, thus, affording the interviewer the chance to gain clarity on any questions about the artifact.
4. The method is flexible enough to allow the exploration of vast ideas or domain specific topics.

Due to COVID-19 restrictions, this research conducted two separate focus group sessions virtually. Individuals who were interested in health dashboards formed the groups. Smaller groups were regarded as the most feasible due to geographic and time constraints (i.e. arranging participants to be, synchronously, at the right place and time), and the level of difficulty in facilitating discussions virtually. The individuals participated of their own accord. In other words, virtual sessions met the realistic demands enforced by COVID-19. The main objective of the focus groups was to uncover new ideas/ opinions that were contrary to what was discovered about dashboards from the literature review; however, ideas/ opinions that aligned with what the literature stated were welcomed to confirm what was already discovered.

6.2. METHOD

6.2.1. Participants

The focus groups had eight individuals who participated. Participants from different demographics and backgrounds were recruited to take part in this research. This resulted in heterogeneous groups that offered a relatively wide range of perspectives and opinions about dashboards. The aim of the focus group was to gain a better understanding of dashboard design aspects through discussions between individuals (participants) that would, idealistically, represent the perspectives of the larger population about health dashboards.

There were two groups and each group was comprised of four participants with different demographics (e.g. male, female, student/ staff etc.). Table 6.1 shows the demographics of all participants. Majority of the participants were familiar with dashboards and used them on often. This puts them in a position to provide valuable information about their experience with using dashboards. The health dashboards (applications) that the users have used and are currently using include Strava, MyFitnessPal, and Oktiv. Non-health dashboards included Windows Server System Dashboard, University Dashboard, and banking applications.

Table 6.1 – Population sample.

Participant	Age Group (Years)	Sex	Highest Education Qualification	Dashboard Usage Frequency
P1	36-55	Male	Master's Degree	Weekly
P2	56 and older	Female	Bachelor's Degree	Now and then (ad-hoc)
P3	36-55	Male	Honours Degree	Weekly
P4	36-55	Female	Bachelor's Degree	Daily
P5	18-35	Female	Grade 12 (Matric)	Never (I don't use dashboards)
P6	18-35	Female	Honours Degree	Daily
P7	18-35	Female	Bachelor's Degree	Weekly
P8	36-55	Male	Honours Degree	Weekly

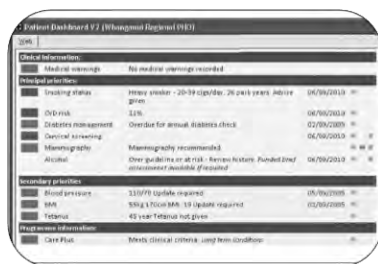
6.2.2. Procedures

Gibson & Arnott (2007), Tremblay et al. (2010), and Goodman et al. (2012) methods (focus group guidelines) were considered, however, they were tailored to the needs/ constraints of the virtual environment. Distance and availability (i.e. due to COVID-19) are the main reasons that led to a virtual (online) focus group. The discussion was based on what was discovered from the literature. As suggested by Gibson & Arnott (2007) and Tremblay et al. (2010), and Brandtner et al. (2015), the topics were predefined (Table 6.2); however, they were only used to guide the conversation to ensure that the participants do not deviate (digress) from the important issues. These topics were structured/ developed around what was understood from the literature (i.e. design aspects that should be included in a dashboard to allow the users to be able to interpret the information easily).

To guide the discussions, dashboard design example were presented to the participants. The dashboard examples were carefully selected to represent the majority, if not all, of the important design aspects discovered from the literature. Thus, allowing the focus group sessions to generate a wide range of views/ opinions/ perspectives that can be analysed for developing a set of guidelines. These dashboard examples were selected (Figure 6.1) based on their differences in design; for instance, dated (Figure 6.1. – “A”) vs modern designs (Figure 6.1. – “B” and Figure 6.1. – “E”), and “list-style” navigation (Figure 6.1. – “B”) vs “drop-down” navigation (Figure 6.1. – “D”). To provide an essence of some of the aspects that were identified in each dashboard example (Figure 6.1), “A” – is a text heavy/ based design (dated dashboard). “B” – the design utilizes a list-styled navigation, progress bars, and information seeking approach. “C” – the design uses a picture/ icon-based navigation, and traffic-light colour-coding system. “D” – the design used a dropdown/ list navigation, information seeking approach. “E” – is a modern design (fitness tracking application) that utilizes data panels, and pictography. The participants examined these dashboard examples to find flaws and suggest improvements.

Table 6.2 – Predefined list of focus group topics covered.

TOPICS DISCUSSED
1. DASHBOARD FAMILIARITY
1.1.Previous dashboard usage 1.2.Level of familiarity
2. DASHBOARD DESIGNS
2.1.Information interpretation 2.2.Opinion on colours 2.3.Navigation layout 2.4.Dashboard simplicity 2.5.Customizability 2.6.Alerts/ reminders/ notification/ warnings 2.7.Other comments (overall impression)



A



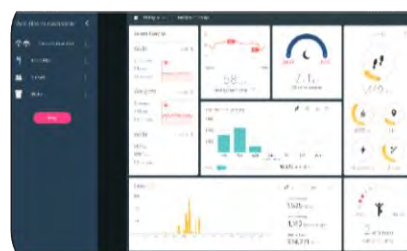
B



C



D



E

Figure 6.1 – Examples of dashboard designs presented to users (A - Sloane et al., 2006; B - McMenamin et al., 2011; C - Bach et al., 2019; D - Giordanengo et al., 2019; E - <https://www.fitbit.com>).

Each session lasted, between one- and two-hour(s) long to allow sufficient information to be elicited from the participants. The focus group was held via Google Meet (<https://meet.google.com>), therefore, all participants were in a comfortable space; and they were not required/ requested to send video feed into the session (i.e. to keep camera-shy individuals calm and relaxed). However, audio and/ or text based (comment section) feedback/ opinions were imperative to allow information to be gathered from the participants; i.e. the sessions were both video and audio recorded. An introduction (objectives, scope) was given to the participants. Due to the restrictions of the virtual environment, the participants had to wait for their turn in order to speak, however, this allowed each participant's view to be expressed fully without interruptions from other participants - this, to a certain degree, created an atmosphere that reassured (reaffirmed) the participants of the importance of every individual's opinion. A set of PowerPoint presentation slides (<https://www.microsoft.com>) were used to guide the sessions, thus, maintaining focus of the participants (discussion) on a particular subject (matter). After all important topics were fully exhausted (i.e. no new information was gathered); the sessions were concluded with closing remarks and salutations.

6.3. Data Analysis

All data collected was transcribed and reflected upon to find any novel ideas that were uncovered during the focus group sessions. Opinions/ ideas provided by the participants were organised (categorised) according to the topics used in the sessions (Table 6.2). Analysis was conducted using Microsoft Word processor (<https://www.microsoft.com>) to find and highlight important ideas (dashboard design aspects) from the data. Common ideas were identified and compared across the groups to find opinion similarities and discrepancies. The ideas were assimilated in order to better understand what the participants found valuable in the design of dashboards; thus, clues on how to design an effective dashboard were uncovered (i.e. the participants provided nuances and confirmed some of the insights found in literature) . The focus group session was guided by predefined topics, therefore, the process of transcription and analysing of data was relatively simple (small dataset). Thus, a more structured/ systematic approach of analysis such as thematic analysis was not required (Braun & Clarke, 2012; Clarke & Braun, 2017).

6.4. RESULTS AND DISCUSSION

The transcribed data presented key dashboard design feature (ideas/ practices) that were important to the participants. The ideas are structured based on predefined topics (Table 6.2) as follows:

6.4.1. Dashboard Familiarity

Majority of the participants used dashboards often (Table 6.1). One participant explained that she had used a “*step counter*” however; she “*struggled with it*”. Therefore, the participants suggested that the dashboard should be designed to effectively present data to the right user; this aligns with Ziemkiewicz et al. (2012) and Ghazisaeidi et al. (2015) who stated that individuals have different cognitive abilities, personalities, tasks, and decision environments, therefore, visualizations should be designed to meet these disparities. A participant mentioned, “*It is important to represent everything in the best way possible – in numbers, in pictures, in dials and things like that...*” and the presentation “*depends on the target audience you are aiming at...*”

Participants mentioned that they preferred a dashboard that presents information in a manner that “*does not require a lot of cognitive effort...*” An effective design allows users to “*present (i.e. data) in different formats*”. A participant used a watch that showed “*that over the past few days I haven’t reached my goal*”. In other words, participants believe that a benchmark (target/ goal) creates a point of reference that allows them to determine how far they are from reaching an ideal health state. This is similar to Franklin et al. (2017) and Horback et al. (2021) who utilized lines and colours as benchmarks in order to indicate a visualization’s change of state, thus, allowing the user to easily discern whether their health is within acceptable bounds or not.

6.4.2. Dashboard Design

INFORMATION INTERPRETATION

Participants suggested that visualizations should be split into separate screens; meaning, “*presenting different graphs individually*” can allow the users to only focus on specific information at a given time; unlike Figure 6.1 – “D”. Detailed information (e.g. tables) should be hidden and only made available on demand; this is to allow users to get further information, when needed, which will assist them in understanding the visualizations further. This is similar

to the information seeking approach suggested by Few (2006), De Croon et al. (2015) and Concannon et al. (2019) that provides summarized data (i.e. overall trend) with the option for users to drill down to specific metrics. Visualizations, such as graphs/ charts, that aggregate data effectively were preferred. Participants also indicate that they *“would almost want to see that information not in tabular format...”* They believe that *“a graph is more of a better display.”*

A benchmark or target (e.g. being able to compare data with a friend) allows the user to be in a better position to understand their progress (i.e. they notice deviations from the ideal health state or goal easily). This is similar to Franklin et al. (2017) and Horback et al. (2021) who used benchmarks that assisted healthcare providers to understand where the patients stood in terms of their health.. One participant stated, *“I would want to see what is the accepted [health metric] for someone who is 38 [years old]”*. Another participant looked at Figure 6.1 – “B” and wanted it to *“indicate how many bars I need to get [to an ideal state]”*. Another participant stated, *“I like to know how I did yesterday, compared to today”*, therefore, a dashboard should allow that comparison to be made easily.

Information that has no context becomes useless to the user. The user sees it as; *“here’s everything but we are not going to tell you about it contextually.”* Context should be provided to the user in order to provide meaning to the information, thus, allowing the user to easily interpret the information being presented; this is similar to the visual integrity principle of Tufte (1983) that states that data should not be quoted out of context by the graphics that present it.

Participants felt that visualizations that are text-heavy (text-based) are time consuming and not interesting (Figure 6.1 – “A”). They would rather have information presented in a graphical format. A visualization *“needs graphics to be engaging.”* If is text heavy it becomes *“a wall of info and can be hard to get the info you want quickly.”* Furthermore, *“there is no patterns therefore increases cognitive load.”*; this is similar to Faiola et al. (2015) who stated that presenting large volumes of complex textual and numeric data cognitively overwhelms the user.

OPINION ON COLOURS

Participants understood the traffic-light colour-coding scheme/ system (red, yellow/ orange, green); therefore, it is an ideal way of indicating different levels of severity to the user. The *“green showed me that I’ve got enough [in this case – sleep] ... red told me that I’ve seriously*

got a problem.” Pemberton et al. (2014), Chandraharan & Arulkumaran (2016) and Vo et al. (2019) find this traffic light colour-coding system as the best way of indicating health risk. In contrary to Figure 6.1 – “C”, the participants also suggest that acceptable/ standardised/ normal colour schemes should be used (e.g. normal red, yellow, and green).

NAVIGATION LAYOUT

Although the navigation depends on the device (e.g. mobile, desktop etc.), the participants suggest that a *“navigation should be simple and easy”* (i.e. “sound” navigation (Yigitbasioglu & Velcu, 2012)) and a navigation bar on the left-hand side of the screen similar to Figure 6.1 – “B” & “C”; this is the most idealistic way for ease of navigation. One participant said *“I’m happy with the [navigation] on the left-hand side... you can choose different options”*. Another participant mentioned that the left-hand side navigation *“is much better... I like that you can click on what you need to see on the left-hand side... better flow...”*

DASHBOARD SIMPLICITY

The participants were displeased with dashboards that were too busy (cluttered); this aligns with Malik (2005), Staron (2015) and Jespersen, (2017) who suggested that dashboard content should be limited to 5-9 (7/ +2) objects per view because only a few items can be kept in the short-term memory at a given time. In a cluttered dashboard, *“eyes aren’t focusing on one thing”*. Participants also do not want to utilize dashboards that have *“too much information.”* They find it difficult to understand the information presented and focus on a single aspect. In other words, the participants felt that each view/ screen of the dashboard should only present relevant information. When participants were shown Figure 6.1 – “D”; one participant stated that *“it’s just a lot of information thrown on top of each other... there’s an overload of information”*. Another participant mention that *“it’s really busy...it’s gonna take me forever to figure out what’s going on”*

CUSTOMIZABILITY

When shown Figure 6.1 – “E”, participants enjoyed the idea of being able to choose what aspects to show on the dashboard or remove in order to show information that is relevant or important to them. This aligned with Hansoti (2010), and Yigitbasioglu & Velcu (2012) who suggested that a dashboard should be customizable in order to cater for different types of user information presentation needs. One participant mentioned, *“I prefer... the ability to edit the dashboard to show your preferred data”*. Another participant stated that the interface should

let one “...choose what you want to see/ you can also remove aspects that you don’t want to show on your dashboard...”

In addition, a participant mentioned, “It would be good if the [visualization] would be customizable for the users” (e.g. being able to change the gauge colour order – “red, yellow & green”, changed to, “green, yellow & red”). Therefore, a way to customize visualizations allows users to be able to fit the visualizations with their “mental schema”; this is similar to the cognitive fit theory that states that data representations should fit with the interpreter’s mental schema, thus supporting problem-solving and decision-making (Teets et al. 2010).

ALERTS/ REMINDERS/ NOTIFICATIONS/ WARNINGS

Participants do not appreciate notifications, especially if they do not have control over how and when (frequency) they can get them. However, they suggested that notifications that contain positive feedback are more interesting and they would rather get those more than negative notification. In other words, the user is likely to continue using the app and maintaining good progress (health) if they receive notification that boost morale. One participant mentioned that notifications are “too annoying... however, it'd be nice to see something positive...” Another participant suggested that “the timing of notification is important... frequent but not too many notifications” Furthermore, another participant suggested a notification “icon on the [dashboard] that will come up but you must be able to switch it off”.

OTHER COMMENTS (OVERALL IMPRESSION)

To reiterate, participants were interested in seeing an overview of information and an option to get details. This is similar to the information seeking approach that provides summarized data and more details on demand (Few, 2006; De Croon et al., 2015; Concannon et al., 2019). In addition, the participants suggested that familiar elements (e.g. icons) would be more useful in letting the user to both navigate and understand the information that is being presented. This is similar to Teets et al. (2010), Dasgupta et al. (2012) and Jespersen, (2017) who mentioned that the correct and familiar visualizations should be chosen, and information should be identifiable and traceable.

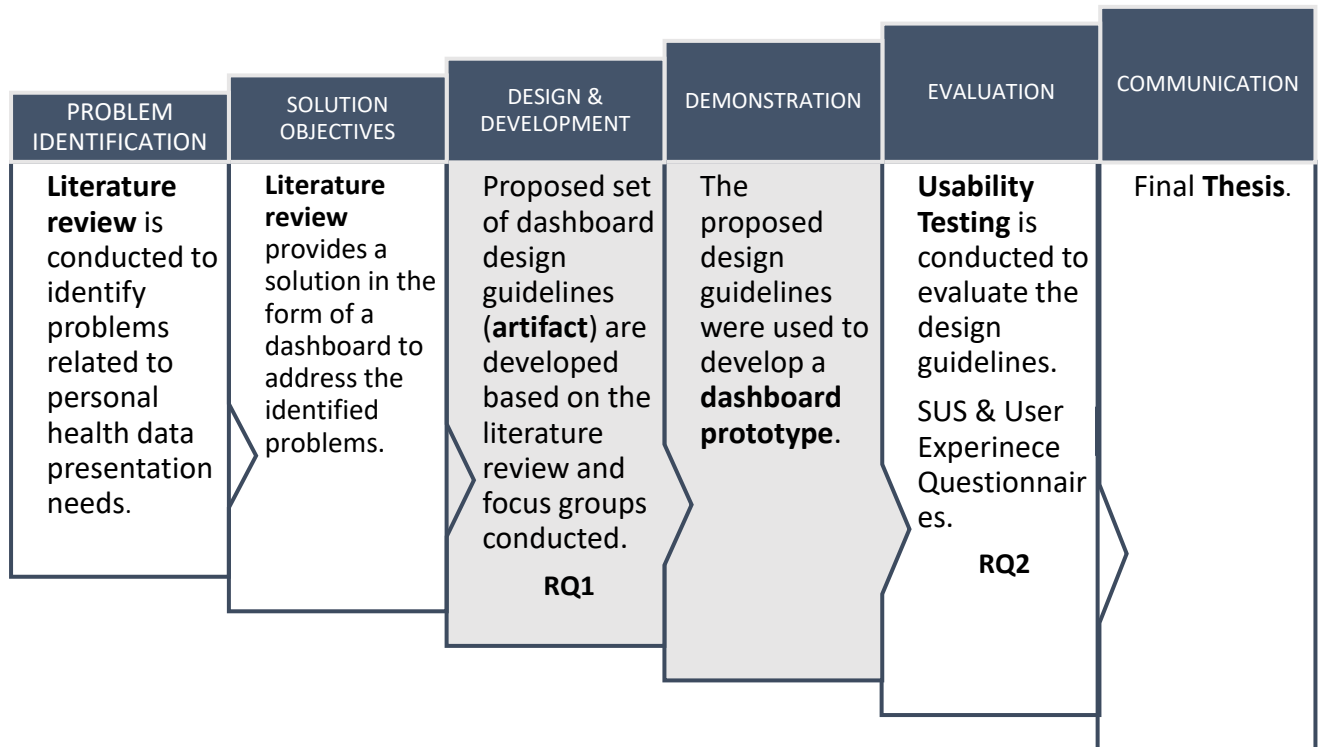
6.5. CONCLUSION

This chapter detailed on what an ideal/ prospective/ everyday user would want from a dashboard design. The chapter presents a few insights about design aspects that are relevant to a user who would want to view information about their health (Table 6.3). The insights learned from this chapter and the previous chapters (literature review) inform the proposed set of design guidelines. The next chapter synthesizes all insights discovered in the previous chapters and presents the proposed set of design guidelines that can be used to develop dashboards for presenting personal health data effectively.

Table 6.3 – *Design aspects that were discovered.*

Categories	Design Aspects
Target audience	<ul style="list-style-type: none"> • Customizability
Display Essential Data	<ul style="list-style-type: none"> • Less information • Minimize clustering (show other visualizations on other screens)
Data Needs Context	<ul style="list-style-type: none"> • Information panel (explanations) • Present information contextually
Layout	<ul style="list-style-type: none"> • Summary only then details on metric/ icon click; presenting different graphs individually • Pictogram navigation and “list” navigation (preference)
Choosing the Display Media	<ul style="list-style-type: none"> • Prefer - Pictograms, familiar icons, graphs, gauges (less tables and text) – depends on the data
Highlighting Important Information	<ul style="list-style-type: none"> • Benchmark/ Target • More Positive and minimal negative Notifications/ feedback
Colour Palette	<ul style="list-style-type: none"> • Traffic-light system is intuitive • “acceptable” colour schemes
Make the dashboard attractive	<ul style="list-style-type: none"> • Prefer dashboards that are well presented (e.g. not dull, clustered and/ or text-heavy)

CHAPTER 7:
PROPOSED DESIGN GUIDELINES



This chapter provides the details of the proposed set of dashboard design guidelines. The guidelines were structured based on categories by Jespersen (2017). Important dashboard design aspects identified from both the literature (Chapter 3, 4, 5, & 6) and the focus groups (Chapter 7) will be presented and consolidated to create a holistic set of design guidelines. The proposed set of guidelines should allow designers/ developers to be able to create a dashboard that can effectively present health information. A medium fidelity dashboard prototype is designed to demonstrate the proposed design guidelines; screenshots of the dashboard prototype will be presented to depict how the guidelines were applied.

7.1. GUIDELINE FORMULATION

The set of guidelines are developed based on the categories found in Table 4.1, which a high-level structure that encapsulates essential design aspects that were discovered by this research. Important design aspects (i.e. from the literature (Chapter 3, 4, & 5) including what was learned from the Chapter 6) were assimilated and aligned to these categories in order to create the proposed design guidelines.

All related theories, principles, guidelines, and designs that were available in the literature are considered to inform the set of design guidelines that would build an effective dashboard. Key

areas that were noteworthy for designing an effective dashboard were discovered. All those areas were placed under the most suitable categories. Table 7.1 provides a snapshot of the insights that were discovered from the literature and the focus groups.

Table 7.1 - Design aspects discovered from the literature review (chapter 3, 4, & 5) and focus groups (Chapter 6).

Categories	Design Aspects
Target audience	<ul style="list-style-type: none"> • Personalization (Chapter 3 & 4) - (Ziemkiewicz et al., 2012; Jespersen, 2017; Visvalingam et al., 2018) • Customizability (Chapter 3, 4, 5 & 6) - (Hansoti, 2010; Yigitbasioglu & Velcu, 2012; Mattingly et al., 2015; Jespersen, 2017) • Cognitive fit theory (Chapter 3) - (Teets et al., 2010; Padilla et al., 2018)
Screen Boundaries	<ul style="list-style-type: none"> • Related data per view/ page (Chapter 4) - (Jespersen, 2017) • Limited scrolling and panning (Chapter 4) - (Cheng et al., 2011; Gunapati, 2011; Zheng, 2017) • Single view/ page (Chapter 4) - (Staron, 2015)
Display Essential Data	<ul style="list-style-type: none"> • 5-9 (7/+2) data elements (Chapter 4) - (Jespersen, 2017) • Essential information only (Chapter 4 & 6) - (Gunapati, 2011) • Summarized/ overview data (Chapter 4) - (Malik, 2005) • Minimize clustering (Chapter 4 & 6) - (Staron, 2015)

	<ul style="list-style-type: none"> • Maximizing the Data-ink Ratio (Chapter 3) - (Tufte, 1983)
Data Needs Context	<ul style="list-style-type: none"> • Data context (Chapter 3, 4 & 6) - (Few, 2006; Dasgupta et al., 2015; Jespersen, 2017; Weggelaar-Jansen et al., 2018) • Messages e.g. “data unavailable” (Chapter 5) - (Swartz et al., 2014) • Visual Integrity (Chapter 3) - (Tufte, 1983) • Information panel (Chapter 6)
Layout	<ul style="list-style-type: none"> • Important data on the Top (left) to right; Comparison groups (Chapter 4) - (Jespersen, 2017) • Multiple windows; Symmetry and proportion (Chapter 3 & 4) - (Malik, 2005; Dasgupta et al., 2015) • Data panels (“summary tiles”) (Chapter 5) – (Mattingly et al., 2015; Gustafson et al., 2018; Bach et al., 2019) • Overview; Zooming/ Filtering; Details on demand (Chapter 3, 5 & 6) - (Few, 2006; Swartz et al., 2014; De Croon et al., 2015; Concannon et al., 2019; Pollack & Pratt, 2020) • Principles of visual perception (Chapter 3 & 4) – (Chen, 2017a; Jespersen, 2017; Pestana et al., 2018; Alrehiely et al., 2020) • Navigation (Chapter 4, 5 & 6) - (Yigitbasioglu & Velcu, 2012; Bach et al., 2019; Zhou et al., 2019)

<p>Choosing the Display Media</p>	<ul style="list-style-type: none"> • Appropriate data medium e.g. icons, tables, text, graphs (Chapter 3, 4, 5 & 6) - (Malik, 2005; Sloane et al., 2006; Gunapati, 2011; Jespersen, 2017; Padilla et al., 2018) • Downloadable reports (Chapter 5) - (Mattingly et al., 2015) • Pull/ push data scenario (Chapter 4) - (Janes et al., 2013)
<p>Display Media Design</p>	<ul style="list-style-type: none"> • Domain specific media (i.e. icons, labels); Uniform medium design (Chapter 4) - (Jespersen, 2017) • Design Consistency (Chapter 4) - (Cheng et al., 2011)
<p>Highlighting Important Information</p>	<ul style="list-style-type: none"> • Highlighting (Chapter 4) - (Jespersen, 2017) • Benchmarking (Chapter 4, 5 & 6) – (Few, 2006; Franklin et al., 2017; (Horback et al., 2021) • Pre-attentive processing (Chapter 3 & 4) - (Janes et al., 2013; Chen, 2017b; Padilla et al., 2018) • Reminders (messages) (Chapter 4, 5 & 6) - (McMenamin et al., 2011; Rouhani et al., 2018) • Graphical Excellence (Chapter 3) - (Tufte, 1983)
<p>Colour Palette</p>	<ul style="list-style-type: none"> • Colour for content clarity; Contrasting colours (Chapter 4) - (Jespersen, 2017) • Neutral colour coding (Chapter 4 & 6) - (Weggelaar-Jansen et al., 2018)

	<ul style="list-style-type: none"> • Colour-coded system (traffic light system) (Chapter 5 & 6) - (Pemberton et al., 2014; Raban et al., 2015; Chandraharan & Arulkumaran, 2016; Bach et al., 2019; Vo et al., 2019) • Minimum use of colours (Chapter 4) - (Staron, 2015) • Same colour gradients/ 2-3 colours (Chapter 4) - (Malik, 2005) • Rules of colour (Chapter 4) - (Pestana et al., 2020)
Make the dashboard attractive	<ul style="list-style-type: none"> ▪ Neat and clean dashboard design (Chapter 4 & 6) - (Jespersen, 2017) ▪ Visualizations should be neat (Chapter 3 & 6) - (Quispel et al., 2018)

7.2. PROPOSED DASHBOARD DESIGN GUIDELINES

This section elaborates on all the important dashboard design considerations that were identified, assimilated, synthesized and categorized into Table 7.2. The guidelines are structured according to categories in Table 4.1 and they encapsulate all the design considerations that were identified from both the literature and the focus group sessions.

Table 7.2 – Proposed dashboard design guidelines.

<p>TARGET AUDIENCE</p> <p>Guideline 1: <u>Provide users with a customizable and/ or personalized interface</u></p> <ul style="list-style-type: none"> ▪ The users’ needs, which are often different from the designer, should be understood and catered for in a good dashboard design. The dashboard may provide users with personalized data or features based on their preferences or activity on the dashboard; i.e. provide users with relevant information/ features on the dashboard when activity resumes (when the dashboard is launched). <ul style="list-style-type: none"> ▪ E.g. overview metrics shown in the morning vs the evening. ▪ In addition, the dashboard needs to be customizable to cater for different users and tasks while displaying relevant information required for making decisions. <ul style="list-style-type: none"> ▪ E.g. overall colour; navigation style; resizing/ rearrangement information/ features etc. <p>Guideline 2: <u>Present data to the users in a familiar manner (format)</u></p> <ul style="list-style-type: none"> ▪ It is imperative to make consideration for the way users want the data to be presented. The data should be presented in a manner that users are familiar with – this allows the user to understand the data intuitively. In other words, there should be a fit between the way data is presented (representation) and the user’s mental schema, thus allowing users to understand the data at first glance. <ul style="list-style-type: none"> ▪ E.g. pictographs that utilize familiar (widely used) pictures/ symbols.
<p>SCREEN BOUNDARIES</p> <p>Guideline 3: <u>Provide a single view/ page (and/ or with limited scrolling/ panning)</u></p> <ul style="list-style-type: none"> ▪ The dashboard should present information on a single screen without (limited) scrolling and panning; scrolling through pages makes it difficult for users to view connections between fragmented data. <ul style="list-style-type: none"> ▪ E.g. buttons for dynamic (additional) information. <p>Guideline 4: <u>Only place related data per dashboard view/ page</u></p> <ul style="list-style-type: none"> ▪ Dashboard elements or data, on a single view or page, should be conceptually and logically related to one another.

- E.g., show one category (related set) of information per view/ page.
- Fragment data into multiple dashboard views in a manner that ensures data that is related (belongs together) is not separated.
 - E.g. separate page/ view for each category (independent data set).

DISPLAY ESSENTIAL DATA

Guideline 5: Present essential data/ information only on the visualization (charts/ graph etc.)

- Maximize data-ink-ratio – the majority of ink used on graphics should present data/information (i.e. not aesthetics). In other words, the dashboard should present essential information only, for analysis purposes; i.e. embellishments/ decorative visual components should be avoided.
 - E.g. limiting colour usage to adding meaning to data only.

Guideline 6: Minimize cluttering on the dashboard

- The content/ data should be limited to ensure that the dashboard display is not cluttered and does not overload or overwhelm the user with information – split the content/ data into several screens/ views. A five-second rule should be followed to ensure the users find what they are looking for in five seconds or less. In addition, there should only be around 5-9 (7/ +2) objects on the dashboard to minimize clustering.
 - E.g. hiding detailed information; split the content/ data into several screens/ views.

DATA NEEDS CONTEXT

Guideline 7: Provide users with data context

- Representations should not lead to misinterpretation or false impressions, and they should not distort the “truth” behind the data. Furthermore, data needs to be contextualized in order for the user to understand the meaning of it. Provide users with cues or messages to allow users to be in a better position to understand what is being presented (or not) on the dashboard.
 - E.g. is a metric indicating good or bad - text/ colour for indicating abnormal data; helpful cues or messages such as “data is unavailable”.

- Provide an information panel/ section/ pop-up for users – to show the importance of keeping the metrics aligned with the goal/ target/ benchmark
 - E.g. what happens when calories burn or what happens when you lose “x” number of calories; pop-up messages to provide warning when vitals are low.

LAYOUT

Guideline 8: Place important information (elements) towards the top and left-hand side (where it’s easily viewed/ accessible)

- Important data should be placed towards the top and left hand-side of the dashboard display; most people read from top to bottom and left to right therefore their eyes are automatically fixed at the top left corner first. The top and / or left-hand side should show noteworthy (newsworthy) information, the middle should present important information, and the bottom and/ or right-hand side should show general information.
 - E.g. show noteworthy (newsworthy/ critical) charts at the top of the screen.

Guideline 9: Follow the principles of visual perception

- Keep the principles of visual perception in mind when organizing elements or data on the dashboard – to identify elements that are enhancements/ pollutants on the dashboard.
 - E.g. placing related charts side-by-side for comparisons.

Guideline 10: Use multiple windows to present independent data

- Present data/ visualizations that are independent to one another in different windows.
 - E.g. showing all critical graphs on one page/ view.
- A maximum of six windows is recommended to ensure that the display is effective – to avoid overwhelming the user with a large number of windows. Uniform sized windows are recommended to ensure the visualizations are given equal importance unless priority has to be given to a single window.
 - E.g. data panels to group related visualizations

Guideline 11: Provide a summary (overview) of data first – information-seeking approach

- Provide users with an overview of information first - a consolidated overview of information to allow users to identify the information that needs their immediate

attention. Allow the users to zoom, search and/ or filter the information - provide enough information to allow the user to determine whether further investigation is required. Lastly, provide the users with the ability to get details on demand i.e. drill down into certain (more detailed) information of interest.

- E.g. summarized information with controls (buttons) for showing more details.

Guideline 12: Place the navigation cluster (list/ tabs/ pictograms) towards the left-hand side

- Provide the users with the ability to navigate through the dashboard easily. A simple navigation “bar” should be placed towards the left-hand side of the dashboard (*Users preferred icons/ pictograms (graphics) with labels for navigation options/ categories; most ideal for small screens (devices). If need be, a list-style navigation may be used for larger screens (devices). However, the navigation design entirely depends on the type of device.*)
 - E.g. icon-based navigation tabs that represent a data-category option.

CHOOSING THE DISPLAY MEDIA

Guideline 13: Use the appropriate display media (i.e. for the right data type)

- The correct media should be used for displaying data - the media that is suitable to convey the message to the user in an effective manner should be selected.
 - E.g. tables – for individual value identification, text – for explanation and supplementing graphics.

Guideline 14: Determine if the dashboard will push information to the user or draw the user to view the information

- The dashboard can “push” information that is important through drawing the user’s attention to unforeseen or unexpected situations.
 - E.g. notification pop-up to grab the user’s attention.
- The dashboard can be used to gain specific information when the user needs it.
 - E.g. offering ways for exploring, filtering, or searching visualizations when needed.

DISPLAY MEDIA DESIGN

Guideline 15: Use uniform display media design

- The display medium should have a similar look across all displays/ windows for a better user experience. Standards for icons and labels that are familiar to the user should be selected to convey data to the user effectively.
 - E.g. widely used icons and labels that are familiar to the user should be consistently utilized across all view/ pages.

HIGHLIGHTING IMPORTANT INFORMATION

Guideline 16: Highlight important information

- Focus the viewer's interest on the main idea instead of how the visual was created; entice the eye to move from one piece of data to another for comparisons, and serve the purpose. Information that needs the immediate attention of the user should be highlighted to ensure it stands out from the rest - this should be done sparingly to ensure it is not overused thus not losing its purpose.
 - E.g. dynamic change of metrics for abnormal values.
- Where possible, provide users with positive notifications/ feedback (rather than negative) and keep the frequency of the notifications at a minimum. The idea is to allow users to be alerted of any values that are sub-optimal while encouraging them to continue using the dashboard for their well-being.
 - E.g. a pop up window or message (with a suggested plan of action) that alerts the user when values are critical.

Guideline 17: Use a salient benchmark to indicate to the users how far they are from reaching a desirable target.

- Provide a benchmark for each visualization (i.e. graph, chart etc.) to assist the user in interpreting the risk being presented by the visualization. This allows the user to quickly/ almost immediately realise they have to make changes/ take actions towards meeting the ideal target (such as calling a doctor, taking medication or increasing daily activity).
 - E.g. a horizontal/ vertical line (on the visualization) that represents an important goal/threshold.

COLOUR PALETTE

Guideline 18: Use appropriate colours for readability and to enhance the data (for interpretability)

- Colour (2-3 colours and gradients of the same colour) should be used to clarify content. Due to individual differences, alternatives (i.e. colour) should be given to the users who prefer not to use “defaults”; while still drawing the attention to the important information. In addition, rules of colour should be kept in mind when selecting colours for the dashboard.
 - E.g. traffic- light colour coding system (red, orange/ yellow, and green) to indicate “progress”/ data changes.

MAKE THE DASHBOARD ATTRACTIVE

Guideline 19: Design an attractive dashboard

- A “minimalist design” should be the goal. In other words, the dashboard should be neat and clean through good visualization design and dashboard theme choices; however, data clarity (interpretability) is still more important.
 - E.g. using material or flat designs, and high-resolution images & text etc.

7.3. APPLICATION OF GUIDELINES

In this section, the proposed guidelines will be demonstrated through a dashboard prototype in order to show how they can be utilized for tailoring dashboards for users. A medium-fidelity dashboard prototype was designed using Axure RP 10 (<https://www.axure.com/>), based on the proposed set of design guidelines. Axure offered a wide range of tools for creating a dashboard prototype that was relative a true depiction of the proposed design guidelines. In this section, screenshots of a medium-fidelity prototype are presented and outlined to indicate how the proposed guidelines were included into the design. Medium fidelity prototypes are fairly complete designs that provide content and layout, navigation, and functionality in “approximate form” for usability validation (Engelberg & Seffah, 2002). A blue box is used to indicate where the guidelines were implemented on each dashboard and each box is numbered (in red) to assist in elaboration.

7.3.1. Target Audience – Guidelines 1 & 2:

Guideline 1: The dashboard prototype provides an essence of personalization for each user. For multi-user dashboard, a nametag is used to notify each user that they are in the right environment (i.e. the right dashboard) (Figure 7.1 - label 1 & 2). The data presented is based on the categories (of health) that the user prefers to view from the dashboard prototype (Figure 7.1 - label 3). The dashboard prototype allows the user to click on the settings icon to open a new screen that allows them to customize the dashboard prototype according to their preferences (Figure 7.1 - label 4). The user has the option to change the dashboard prototype colour, and add/ remove certain categories to the dashboard (Figure 7.2 - label 5).

Guideline 2: Gauges were commonly used in the dashboards that were discovered in the literature (Chapter 5) therefore, similar gauges are used in order to convey the information to the user, in a familiar manner (Figure 7.1 - label 3).

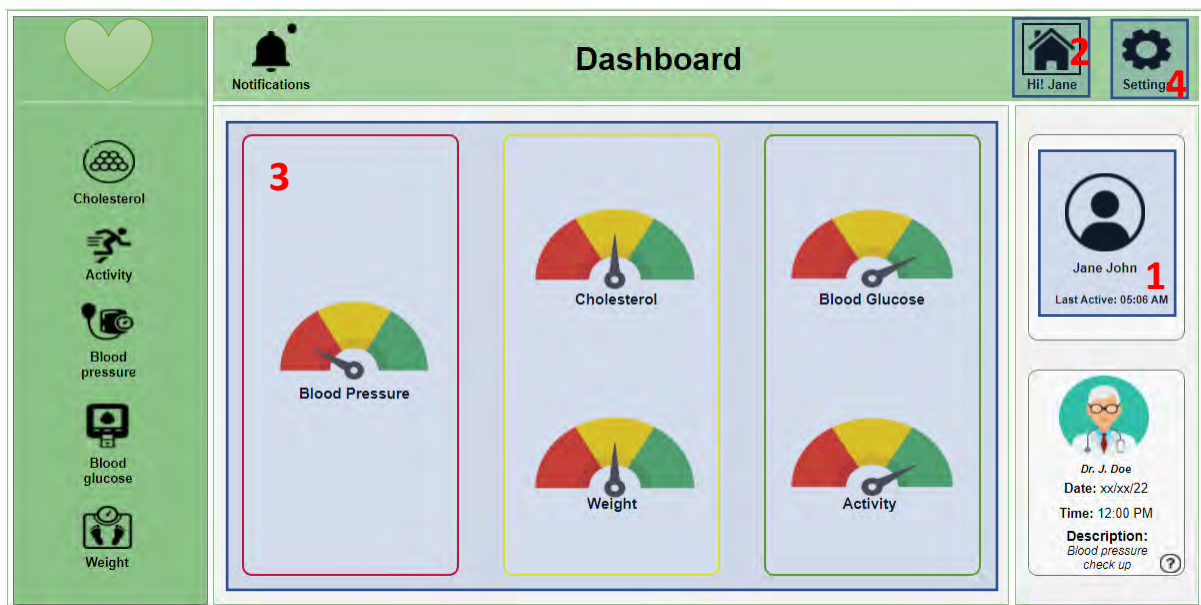


Figure 7.1 – The landing screen or overview screen of the dashboard prototype.

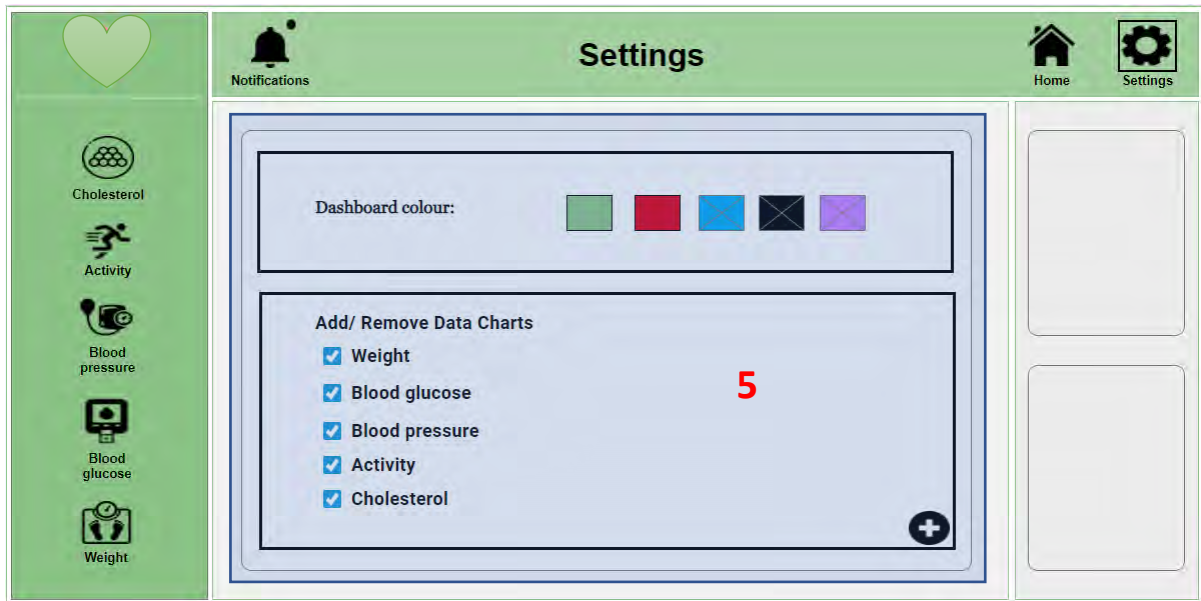


Figure 7.2 – The settings screen where the user can change certain features of the dashboard prototype.

7.3.2. Screen Boundaries - Guidelines 3 & 4:

Guideline 3: The information is presented in a manner that does not require the user to scroll or pan in order to see all data. The user is provided with options (Figure 7.3 - label 3) in order to interact with the information. Therefore, to view all aspects related to a specific category, the user does not have to change screens (views/ pages).

Guideline 4: Once the user clicks on each category (Figure 7.3 - label 1), the user is presented with information that is only related to the category (e.g. cholesterol information – Figure 7.3 - label 2).

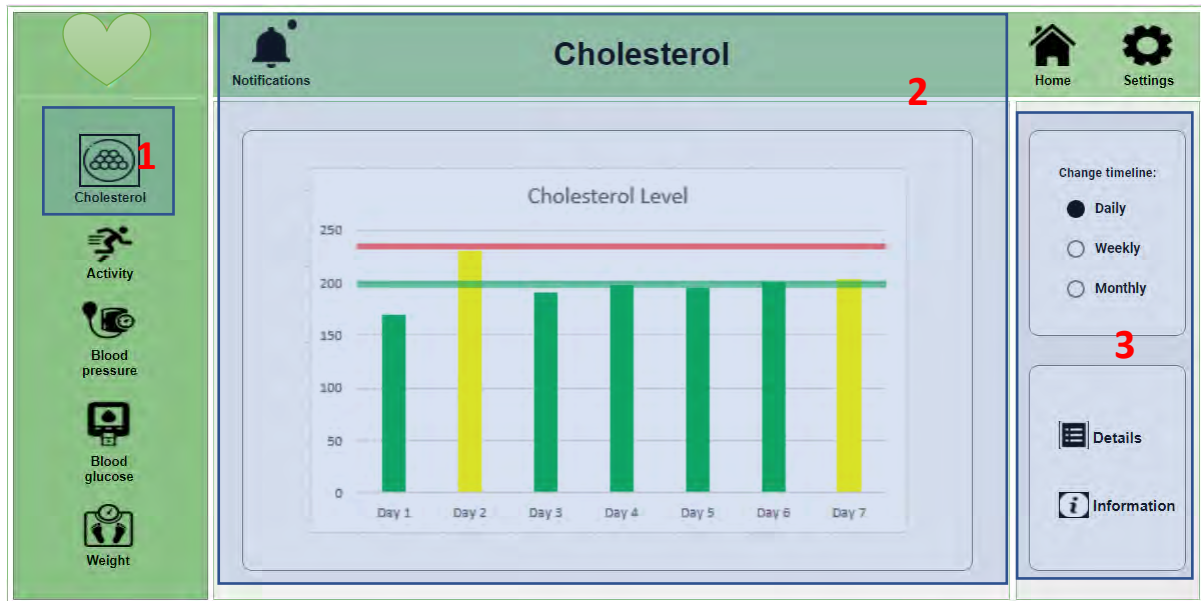


Figure 7.3 – A view (screen) for all cholesterol information (day graph).

7.3.3. Display Essential Data – Guideline 5 & 6:

Guideline 5: only essential elements were used to visualize (graph) the health information; i.e. all elements used are necessary to convey the meaning of the data that is presented (Figure 7.4 - label 1).

Guideline 6: The screen (Figure 7.4) only contains a few elements that are necessary to present the information; clutter was minimized by only showing one visualization (e.g. graph state) at a time (Figure 7.4 - label 1). To avoid bombarding the user with information, the rest of the health information is hidden until the user changes (Figure 7.4 - label 2) the state of the visualization.

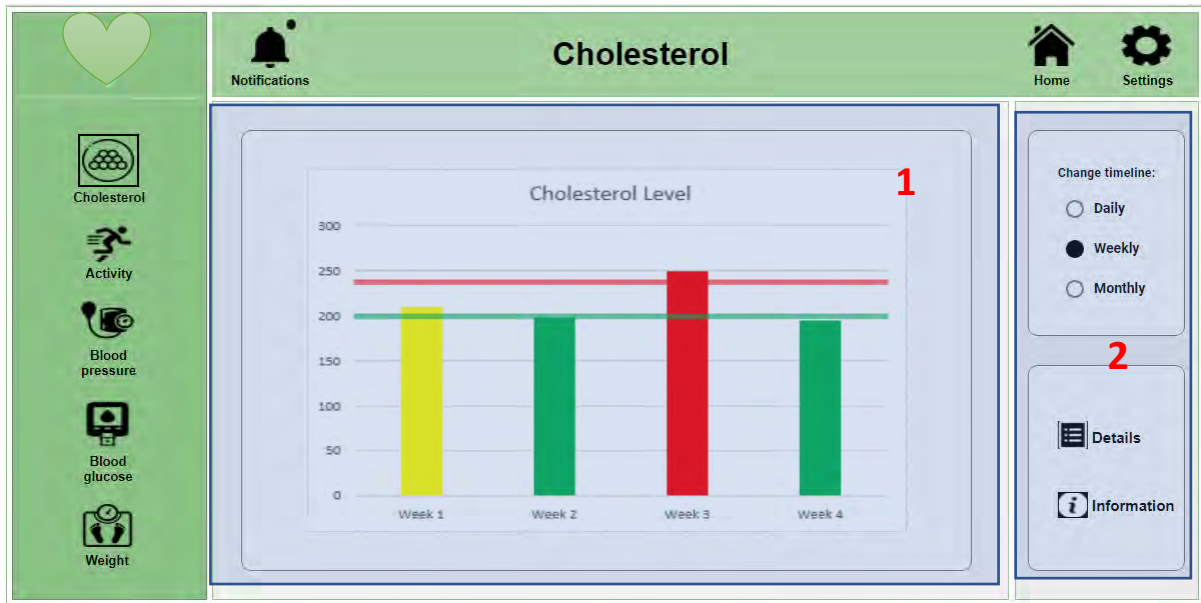


Figure 7.4 – A view (screen) for all cholesterol information (week graph).

7.3.4. Data Needs Context – Guideline 7:

Appropriate headings, labels, and values have been used in order to make the user aware (orientation) of the data, they are viewing (Figure 7.5 - label 1 and 2). Users can click on the information icon (Figure 7.6 - label 3) in order to gain more information about the category (Figure 7.6 - label 4). This allows the user to be in a better position to understand the meaning behind the information (visualizations).

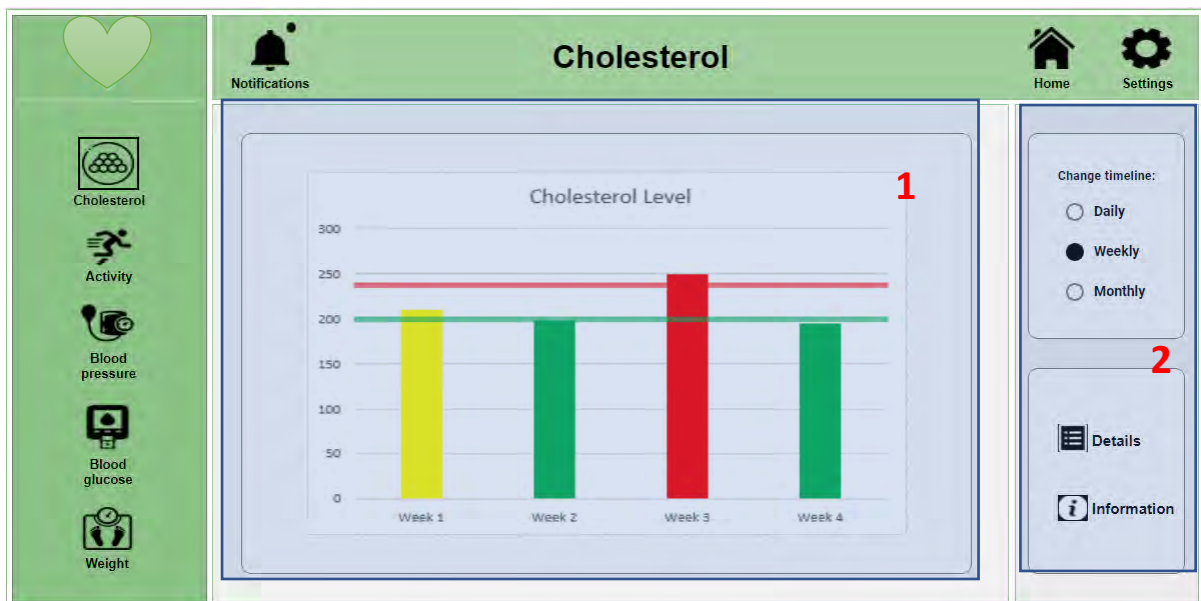


Figure 7.5 – A view (screen) for all cholesterol information (week graph).

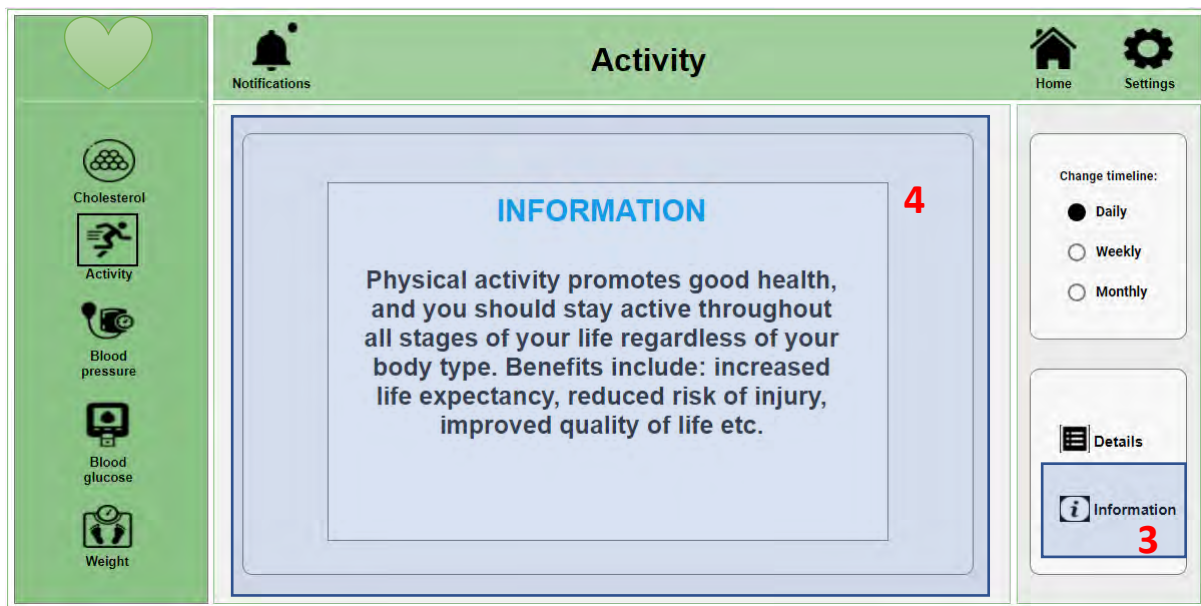


Figure 7.6 – Information panel that provides users with information about the category (activity information screen).

7.3.5. Layout – Guideline 8, 9, 10, 11 & 12:

Guideline 8: the most critical categories are placed on the left (Figure 7.7 - label 1) and at the top (Figure 7.9 - label 5) of the dashboard prototype to give them priority.

Guideline 9: The visualizations (gauges) are grouped according to their severity (Figure 7.7 - label 1). The visualizations (Figure 7.7 - label 1) are separated from the user's and the doctor's information (Figure 7.7 - label 3).

Guideline 10: Different categories/ visualizations are grouped and presented based on the level of severity (only three “windows”/ groups are presented) (Figure 7.7 - label 1).

Guideline 11: A summary of all categories was presented on the landing (overview) screen (Figure 7.7 - label 1). The visualizations change when the user hovers over them (Figure 7.8 - label 4) to a pop-up visualization that can be clicked on to get more details.

Guideline 12: The navigation cluster is placed on the left side to allow the users to switch from one view/ screen to the next. In addition, labels and icons were used to represent each category (Figure 7.7 - label 2).



Figure 7.7 – The landing screen or overview screen of the dashboard prototype.

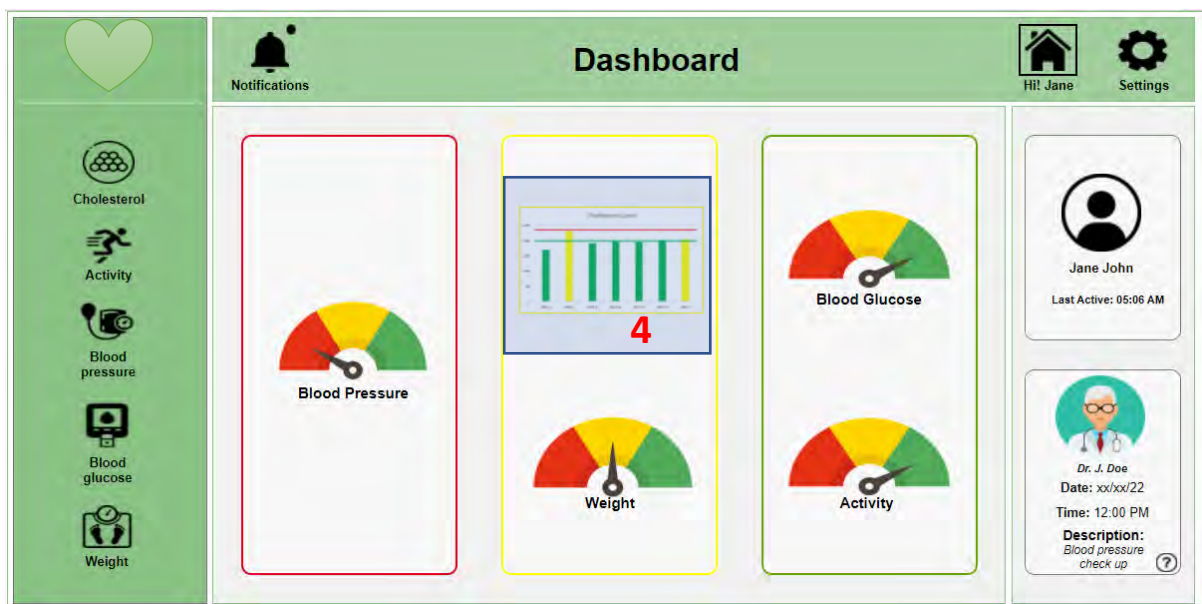


Figure 7.8 - The landing screen or overview screen of the dashboard prototype (with cholesterol hovered).

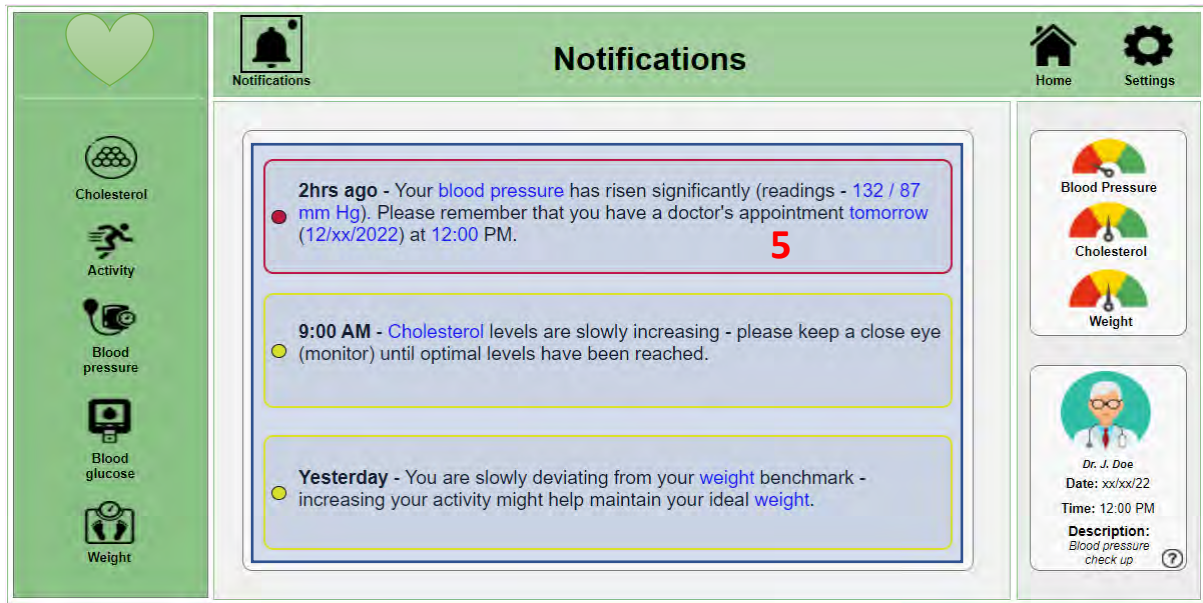


Figure 7.9 – Notifications screen.

7.3.6. Choosing the Display Media – Guideline 13 & 14:

Guideline 13: The dashboard prototype used a bar chart to present the cholesterol information, which relatively fits the metric system used for cholesterol data (Figure 7.10 - label 1).

Guideline 14: the dashboard prototype allows the user to further explore their health data on their own accord to understand their health (Figure 7.10 - label 2).

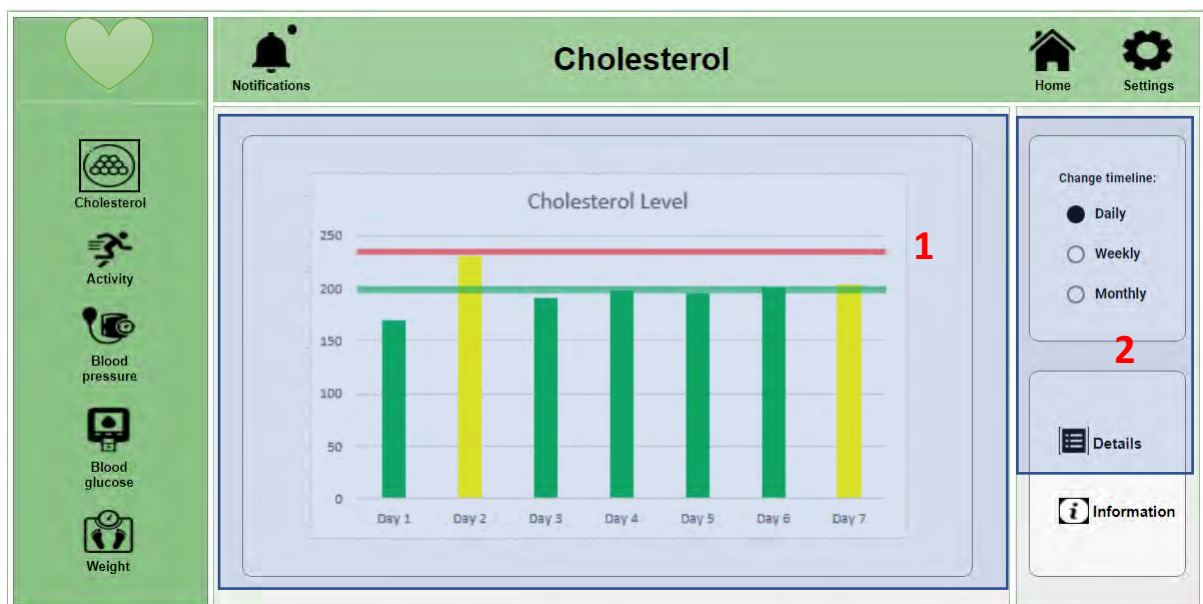


Figure 7.10 – A view (screen) for all cholesterol information (day graph).

7.3.7. Display Media Design – Guideline 15:

All windows, icons and labels were kept uniform across all dashboard prototype screens to allow the user to navigate through the dashboard prototype easily (i.e. users do not have to relearn each screen in order to work their way through the dashboard).

7.3.8. Highlighting Important Information – Guideline 16 & 17:

Guideline 16: The important notifications were placed at the top with a red border to show the level of importance and severity (Figure 7.11 - label 1). The goal was to present the notifications in a manner that allows the user to detect anomalies easily without feeling distress (e.g. providing the users with a plan of action such as informing them to remember to see the doctor).

Guideline 17: Horizontal lines were used on the graph in order to convey abnormal values (that breach the benchmark) to the user quickly and easily (Figure 7.12 - label 2).

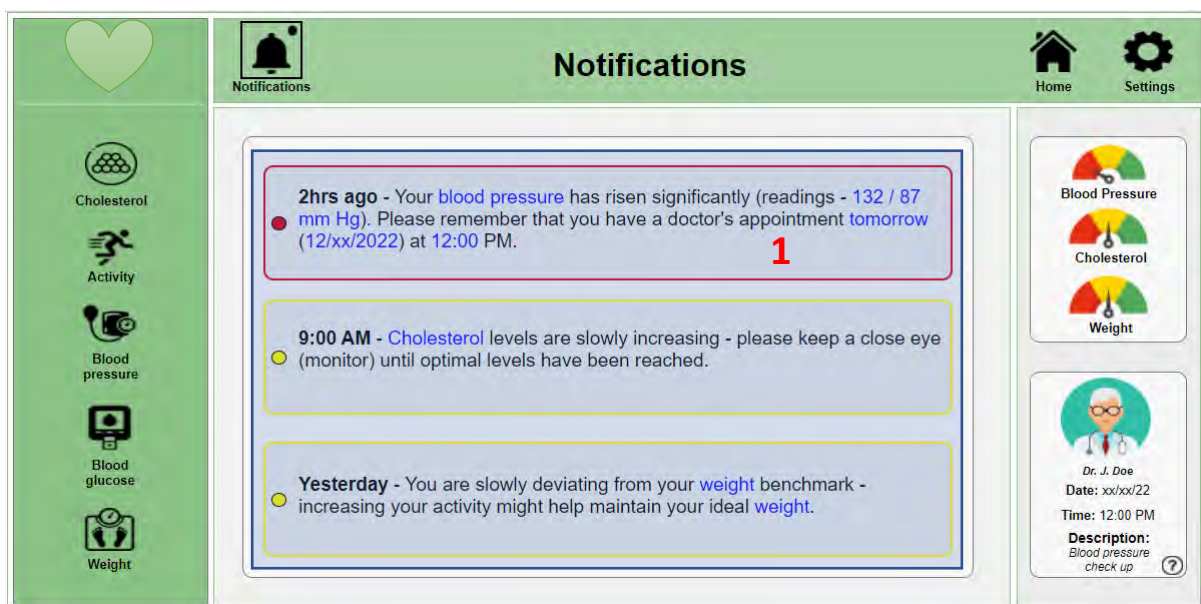


Figure 7.11 – Notifications screen.

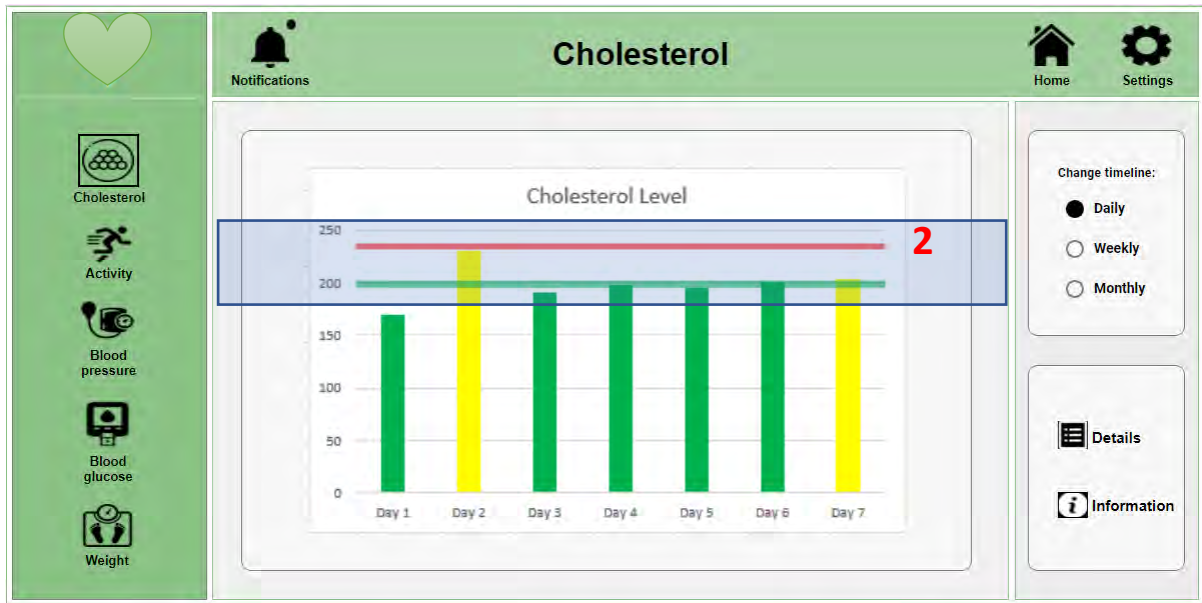


Figure 7.12 – A view (screen) for all cholesterol information (day graph).

7.3.9. Colour Palette – Guideline 18:

A traffic light colour-coding system (red, yellow, green) is used to show values that are in abnormal range and those in the normal and acceptable ranges (Figure 7.13 - label 1). Apart from the colours used to convey the meaning of data, the dashboard prototype only has three colours (Grey, Green and black).

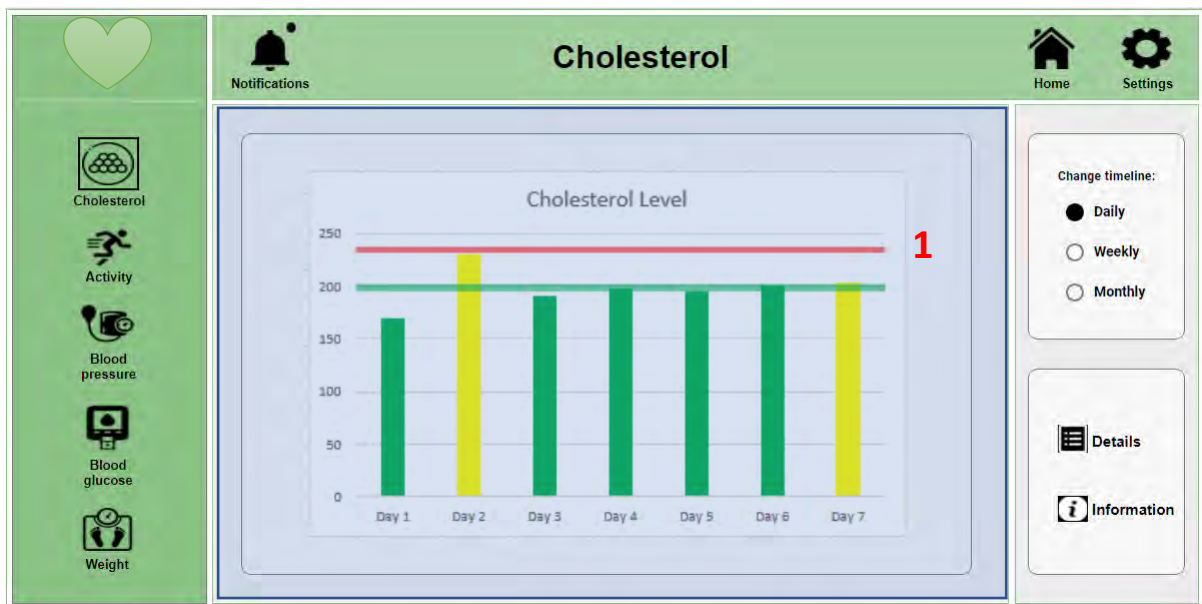


Figure 7.13 – A view (screen) for all cholesterol information (day graph).

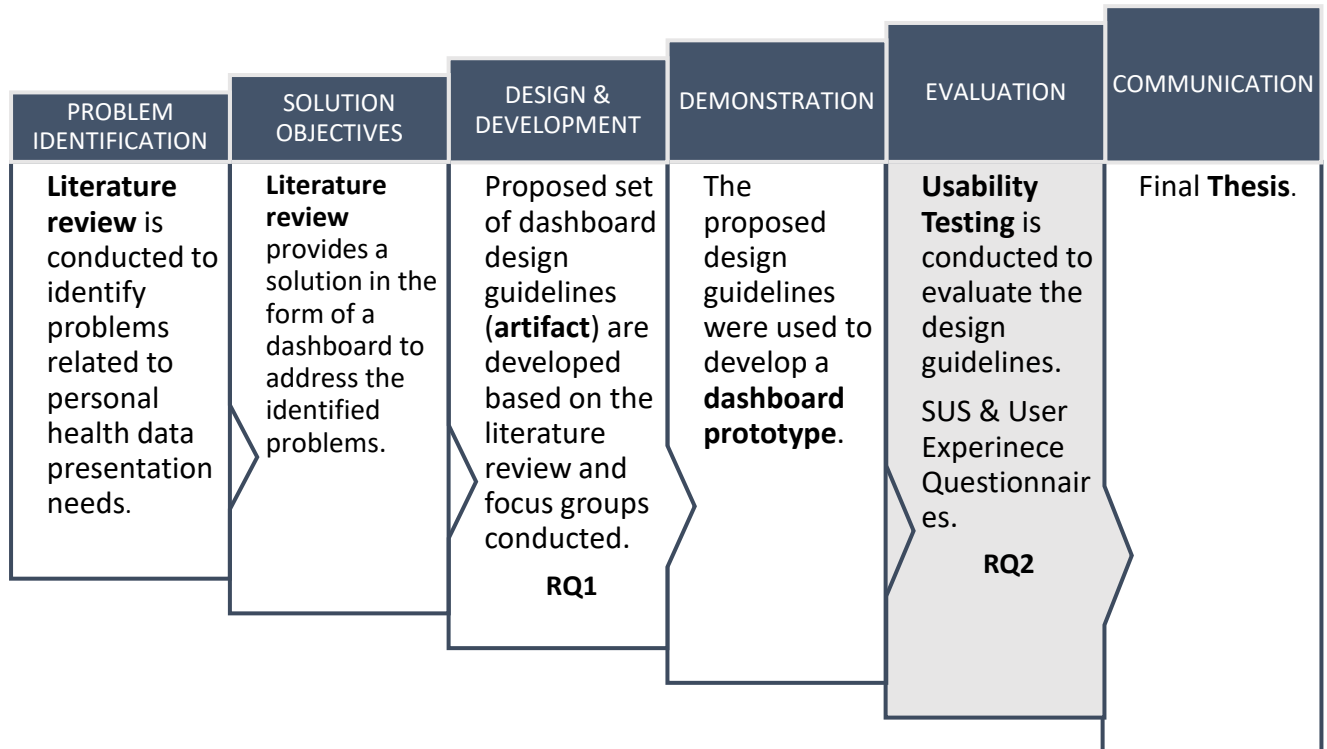
7.3.10. Make the Dashboard Attractive – Guideline 19:

The dashboard prototype was designed to be simple, clean and easy on the eye, therefore, it is relatively attractive. Fairly high-resolution images were utilized and data was presented in a simplistic manner. All elements were organized properly across all views of the dashboard prototype.

7.4. CONCLUSION

This chapter outlined and presented a proposed set of dashboard design guidelines that can be used to effectively present health information. The guidelines were used to develop a dashboard prototype. A medium-fidelity dashboard prototype resulted from the application of the proposed design guidelines. The dashboard prototype demonstrates how the guidelines can be utilized for designing an effective dashboard. The next chapter focuses on evaluating the dashboard design in order to further assess the practicality (feasibility) of the proposed set of guidelines for designing a dashboard that effectively presents/ communicates personal health data (holistically).

CHAPTER 8:
GUIDELINE EVALUATION



In this chapter, the effectiveness of the guidelines are evaluated through a dashboard prototype. The rationale for using usability testing as an evaluation method, in order to evaluate the designed dashboard prototype will be outlined. The evaluation will examine the dashboard prototype, thus, determining the level of utility and efficacy of the proposed guidelines. Furthermore, the evaluation was done to learn new insights that may enhance the quality of the proposed set of guidelines.

8.1. EVALUATION AND DESIGN SCIENCE RESEARCH

Chapter 2 presented a framework by Venable et al. (2012) that can be followed to evaluate artifacts (Table 8.1). To evaluate the proposed design guidelines (artifact), an ex post – naturalistic evaluation (i.e. evaluating an instantiation in an idealistic/ realistic setting) was conducted on the dashboard prototype (instantiation). Ex post evaluation deals with an instantiated artifact (dashboard prototype); Naturalistic evaluation assesses the extent to which the artifact solves the problems in a real-world environment (i.e. addresses the complexities of real people, systems and settings; this is the goal of this research).

Table 8.1 - Design science research evaluation framework (Venable et al., 2012).

DSR Evaluation Method Selection Framework	Ex Ante	Ex Post
Naturalistic	<ul style="list-style-type: none"> • Action Research • Focus Group 	<ul style="list-style-type: none"> • Action Research • Case Study • Focus Group • Participant Observation • Ethnography • Phenomenology • Survey (qualitative or quantitative)
Artificial	<ul style="list-style-type: none"> • Mathematical or Logical Proof • Criteria-Based Evaluation • Lab Experiment • Computer Simulation 	<ul style="list-style-type: none"> • Mathematical or Logical Proof • Lab Experiment • Role Playing Simulation • Computer Simulation • Field Experiment

Participants were observed (behaviour/ actions) while they complete tasks with the prototype provided. Furthermore, the participants completed post-evaluation surveys (System Usability Score and User Experience questionnaire). This evaluation was done to determine the effectiveness of the dashboard design guidelines.

To conduct the evaluation of the instantiation (dashboard prototype), this research utilizes the four step process provided by Venable et al. (2016) to inform the decision of choosing the best evaluation strategy. The steps include:

- **Step 1: Explicate the goals of the evaluation**

Design science research has four possible goals; rigour, uncertainty and risk reduction, ethics, and efficiency (Venable et al., 2016). This research looks at rigour to ensure that the dashboard design guidelines are appropriate; this is done through evaluating the effectiveness of the dashboard prototype via a naturalistic evaluation.

- **Step 2: Choose the evaluation strategy or strategies**

The social and technical uncertainty and risks are low (Figure 8.1). Therefore, a quick and simple strategy is the most suitable choice to evaluate the small-scale (relatively simple) medium-fidelity prototype that requires a few evaluation resources (only time and readily available equipment – e.g. computers, recording devices etc). Due to time-constraints, this strategy was ideal for performing only one iteration of the evaluation process.

<i>DSR evaluation strategies</i>	<i>Circumstance selection criteria</i>
Quick & Simple	If small and simple construction of design, with low social and technical risk and uncertainty
Human Risk & Effectiveness	If the major design risk is social or user oriented and/or If it is relatively cheap to evaluate with real users in their real context and/or If a critical goal of the evaluation is to rigorously establish that the utility/benefit will continue in real situations and over the long run
Technical Risk & Efficacy	If the major design risk is technically oriented and/or If it is prohibitively expensive to evaluate with real users and real systems in the real setting and/or If a critical goal of the evaluation is to rigorously establish that the utility/benefit is due to the artefact, not something else
Purely Technical Artefact	If artefact is purely technical (no social aspects) or artefact use will be well in future and not today

Figure 8.1 - Evaluation strategy selection criteria (Venable et al., 2016).

- **Step 3: Determine the properties to evaluate**

All design aspects (i.e. user interface and user experience related properties) of the dashboard prototype are evaluated – through a naturalistic evaluation – to determine whether the design guidelines can be used to develop an effective dashboard (i.e. that presents health data/ information in an easily interpretable manner);

- **Step 4: Design the individual evaluation episode(s).**

All design aspects of the dashboard prototype have the same level of importance. The evaluation (participant observation and surveys) of the dashboard prototype will run for five sessions (episodes) and requires resources such as time (30-60 minutes per session), people (five participants – one per session), equipment (laptop, secondary monitor, and an audio recording device), and research site (Atrium – Rhodes University IS Department Building).

8.2. RATIONALE FOR USABILITY TESTING

Chapter 4 indicated that a “*Dashboard = Data + Visualization + UI*” (Zheng, 2017). In order to ensure all those aspects are catered for by the design guidelines, usability testing was deemed the most appropriate method to evaluate the design guidelines (i.e. through the dashboard prototype). Usability testing can be defined as any method (technique) that collects data through a systematic (structured) user interaction that requires specific (goal-oriented) tasks to be completed under controlled conditions (Wichansky, 2000; Goodman et al., 2012). This research utilizes this technique in order to examine the fit (usefulness) between the dashboard prototype and the user; thus, understanding the degree to which the dashboard’s design supports their tasks; i.e. it assesses the effectiveness of the dashboard prototype. The usability testing sessions were conducted in a “test room” where participants are invited to and observed while completing specific tasks. The sessions were audio/ video recorded, transcribed and analysed (coded) to find meaningful patterns (e.g. difficulties, frustrations, confusion, satisfaction etc.) (Bastien, 2010). The main goal of usability testing is to discover and rectify usability issues found in the dashboard prototype design. All problems found provide valuable insights that can contribute to the proposed design guidelines (Hartson et al., 2003; Campbell,

2011). Therefore, usability testing addresses the RQ2 (Chapter 1) by determining the efficacy and utility of the design guidelines (i.e. through the dashboard prototype evaluation).

There are two types of evaluation that can be conducted, namely: formative (less formal) and summative (formal) evaluation. Formative evaluations are conducted during the development process to find usability problems and make design improvements; summative evaluation is only conducted after development to examine the level of usability achieved by the design. Summative evaluation focuses on quantitative data such as user performance metrics and formative evaluation is more concerned with qualitative usability data such as identified usability problems (Hartson et al., 2003). This research focused on formative evaluation to find qualitative data (dashboard features) that can be used to improve our set of guidelines.

Furthermore, usability tests can be either very formal or informal. For instance, the observer watching through a one-way-mirror, sitting next to and watching the user, or observing the on-screen behaviour of the user while conducting the tasks specified (Campbell, 2011). This research aimed at conducting a more formal approach; i.e. sitting next to and observing the user's on-screen (primary) behaviour via a secondary screen. User-, Inspection – and Model based evaluations are the standard techniques used to evaluate user interfaces. This research used the user-based evaluation (method). User based evaluations require users to participate directly. The users are invited to a session where they are prompted to complete a number of, typical, tasks on the dashboard prototype; they can also explore the dashboard freely. The researcher observes and records the flaws or difficulties experienced/ identified by the user. The identified insights are used to make improvements to the design guidelines (Bastien, 2010).

Usability tests can be conducted on both low- and high-fidelity prototypes. Low-fidelity prototypes are regarded as freehand-sketched (i.e. with “little or no interactive functionality”) designs that provide a high-level depiction of the interface; while high-fidelity prototypes are highly-functional designs that provide a “lifelike simulation” of an interface (Engelberg & Seffah, 2002). This study made use of a medium-fidelity prototype for evaluating the proposed set of design guidelines. There is no “one-size-fits-all” approach to designing dashboards; therefore, a quick, simple and low cost prototype (i.e. medium-fidelity) that encapsulated majority of the proposed design guidelines was regarded as sufficient for evaluation. Nielsen (2000) has indicated that 4-5 users can identify 80-85% of user interface problems. During each session of the usability tests, the user has to be prompted or trained to think aloud while completing each task; to gather serendipitous ideas that would have otherwise not been thought

of; thus, the discovery of new insights for the design guidelines (Bastien, 2010; Campbell, 2011).

8.3. METHOD

8.3.1. Participants

This research aims at understanding the needs of wide range of prospective dashboard users; therefore, it welcomed five participants from different age, sex and educational background. All participants were new (not part of the focus group session) in order to gather new insights (Table 8.2). Majority of the participants were well familiar with dashboards and used them often (Table 8.2). The health dashboards that were previously and currently used by the participants include health tracking, fitness tracking, and period tracking dashboard; other dashboards include finance, in-game, and productivity dashboard.

Table 8.2 – Population sample (Usability Testing).

Participant	Age Group (Years)	Sex	Highest Education Qualification	Dashboard Usage Frequency
P1	56 and older	Male	Master's Degree	Weekly
P2	36-55	Male	Doctorates Degree	Weekly
P3	18-35	Female	Honour's Degree	Monthly
P4	18-35	Male	Bachelor's Degree	Daily
P5	36-55	Female	National Diploma	Daily

8.3.2. Procedure

8.3.2.1. TESTING SETUP

For each usability test session, a testing station was set up in a quiet room. The testing station included a participant-facing monitor (including a mouse and keyboard) connected to the research laptop via a HDMI cable. The research laptop ran the dashboard prototype via Axure RP 10 (<https://www.axure.com/>) and presented it to the participant-facing monitor. A recording device (“Olympus WS-853” digital voice recorder) was used to capture participant feedback, while a screen capturing software (Screencast-O-Matic - <https://www.screencast-o-matic.com/>), installed on the laptop, and was used to record the participants’ interaction with the dashboard prototype.

8.3.2.2. PROTOTYPING TESTING

Pilot Test: a pilot test was conducted to ensure that all aspects of the dashboard interface were working and would allow the participants to successfully complete each task. Any technical issues that arose during the pilot test were addressed ensuring that the user sessions (i.e. usability testing) ran smoothly.

Usability Testing: Independent sessions (that lasted for about 30 minutes) were conducted, where each user was given an opportunity to utilize the dashboard prototype and find the flaws. Upon arrival, the participants were shown to their seat and provided with preliminary information to clarify their importance further and role in the usability test sessions. The participants were provided with five tasks (Table 8.3) to complete on the dashboard prototype. Each task was designed to ensure that the participant engaged with aspects of the dashboard design that were based on the guidelines proposed (Chapter 7). For example, Task 3 (Table 8.3) encapsulates Guideline 2, 4, 5, 6, 9, 13, & 17 (Table 7.2). After each task, a discussion around four topics (data interpretation (health risk), data presentation opinions/ suggestions, notification opinions/ suggestions, and dashboard feature opinions/ suggestions) was conducted for further investigation. A think-aloud technique was used and the participants were encouraged to speak out their thoughts as they completed the tasks (Campbell, 2011). This allowed insights to be discovered about the difficulties that participants were experiencing. At the end of all the tasks, the participants were asked general questions based on eight topics (Table 8.4) to gather overall impressions of the dashboard prototype. In addition, participants

were asked to complete two post-evaluation questionnaires (Section 8.5), 1) System Usability Scale (SUS), and 2) User Experience Questionnaire (UEQ) (Brooke, 1996; Schrepp, 2019).

Table 8.3: Tasks that were conducted during usability testing.

Tasks
<p>T1. Finding abnormal information</p> <ul style="list-style-type: none"> • You want to find the metrics that are in the abnormal range.
<p>T2. Finding doctor-related information</p> <ul style="list-style-type: none"> • You want to see when the next doctor’s appointment is.
<p>T3. Finding specific data</p> <ul style="list-style-type: none"> • You want to check the state of your cholesterol in “Week 3”. • You want to check the value of your cholesterol on “Tuesday – Week 2”. • You want to learn more information about the benefits of being active.
<p>T4. Understanding notifications (highlights)</p> <ul style="list-style-type: none"> • You want to see feedback (messages) on the state of your health.
<p>T5. Customizing the dashboard</p> <ul style="list-style-type: none"> • You want to customize the dashboard by removing the weight (category) and changing the dashboard colour to red.

Table 8.4: General topics that were discussed after all tasks were completed.

GENERAL QUESTIONS (TOPICS)
<ul style="list-style-type: none"> • First thing noticed. • Unfamiliar elements. • Navigation difficulties. • Dashboard usefulness. • Information presentation. • Health risk. • Design attractiveness. • Other comments (positive/ negative aspects and improvements/ suggestions).

8.4. RESULTS AND DISCUSSION

This section presents all insights that were gained during all usability evaluation sessions. Similar to the Chapter 6 - Section 6.3, the recorded information was transcribed to extract valuable insights that were learned from the sessions. This section is divided based on the tasks and questions that were utilized in the usability evaluation sessions.

8.4.1. Tasks and Discussions

FINDING ABNORMAL INFORMATION

The participants understood the overview of data presented in gauges. The traffic-light colour coding system was easy to interpret; it allowed them to understand what part of their health is at risk. By looking at the colours, one participant mentioned that *“everything in the green shows that everything is supposed to be good... when it’s in red I suspect that’s where something is some sort of wrong or abnormal”*. Another participant guessed that *“anything in the red would be”* something to be *“concerned about... the orange... it’s something to keep an eye on... the green means I’m in the clear, that’s within normal levels”*

FINDING DOCTOR-RELATED INFORMATION

The participants were able to locate the doctor’s information easily, however, some participants first intuition was to click on the features in the “doctor” window in order to see more details about the doctors, appointments, highlights, and related information. One participant presumed *“that the date... should be the one that is telling me I should go see the doctor”*. Another participant identified that *“...there’s also a question mark there and I guess maybe I could click on that... although, I guess I can see I don’t need to leave... it says it here [the doctor’s information]...”* In other words, the participants understood the information that was being presented however; they wanted to interact with the information in order to get further information. This is similar to the information-seeking approach that is used by De Croon et al. (2015), Concannon et al. (2019), and Jin & Li (2019) to allow users to get details from a summarized data view.

FINDING SPECIFIC DATA

The participants were able to find and understand the information presented. The users felt that the layout was relatively simple to use for accessing all aspects of the presented data. The benchmarks (horizontal red and green lines) used allowed the users to interpret the information

and understand their health risk easily. A participant mentioned that they would also want to see - *“what's the normal range?”* Another participant felt *“like everything [presented is] relatively easy to get access... I actually understand what is going on... The layout is pretty simple”*. The participants assumed that the *“green line is like where it [i.e. value or metric] should normally be... the red line is like, when it's dangerously high...”* and they *“figured it out pretty quickly”* that it was similar to *“robot [traffic light] coding...”*

One participant did not appreciate the specific values shown on that graphs (e.g., *“What is ‘250’? ‘300’? I have no idea...”*) and would rather want to be informed of the general trend (e.g. via a *“trendline”*) of the information. The participant said, *“I'm not going to remember random figures of human health... ‘200’ ...what does it mean... even if I knew the units... I still don't know what it means... I can't interpret it...”* This is similar to the information seeking approach that hides detailed information (i.e. textual and numeric data) for later (De Croon et al., 2015; Concannon et al. 2019; Jin & Li 2019).

Another participant hovered (tried to click) over the values on the graph to drill down to more details; instead of the button offered to the user in order to view detailed information. The user suggested *“a pop up”* when a value is hovered or clicked on to show another graph.

The information panel seemed to lack important information according to the participants. The users felt that it was only showing general information only and not plans of action for abnormal metrics. One participant mentioned, *“as much as this information is giving me the benefits of being healthy... the best part would be showing tips on how to actually maintain my health”*. When shown an activity data, a participant said, *“I suppose it's how you do that physical activity so you don't want to injure yourself... So maybe there are some sort of qualifiers that... if you've been up at sedentary and suddenly you've got to start exercising, you might heighten your risk of injury... so maybe you just want to say there that should we seek the advice of a doctor, practitioner, or fitness trainer...”* In other words, the participant indicated that it is important that the dashboard provides information about how to take care of oneself to avoid exacerbating a critical condition. Another participant would rather have the information split and presented along with picture (icons, photographs etc.) to provide better context (e.g. *“so, you'd have like a picture and then the first sentence and then you have another picture...”*). Furthermore, a participant suggested that trustworthy-source links be provided for further information that is not presented on the dashboard.

UNDERSTANDING NOTIFICATIONS (HIGHLIGHTS)

The participants mentioned that they “*like the colour coding*” and understood the colour coding used. One participant said, “*the colour coding does allow me to see which one is of importance and which one I can just keep a close eye on...*” Although, one of the participants tried to click on the notification to view more details, they felt that the notifications were “*a bit wordy*”, and only a highlight (i.e. a small note) of the notification should be presented with an option to view more details. Furthermore, the participants suggested, “*maybe the notifications need to be split... I'm suggesting that we just have some sort of categorization ...*” In other words, providing an option to either categorizing the notifications or viewing all of them in a list form would be suitable. The participants also mentioned that they “*kind of... wish it [notification] would give me something to do...*” with regards to a plan of action where values are in the abnormal range. A participant suggested, “*instead of the [dashboard] constantly reminding me about my health...the app could probably prompt me to do activities to get my health back in order.*”

In addition, a participant suggested a calendar that visualizes all-important dates/ activities and a reminder to do activities such as booking the appointment, request medication refills etc.

CUSTOMIZING THE DASHBOARD

The participants suggested that the dashboard should offer, “*more colours that [they] can work with*” and to allow a user “*to rearrange categories*”. The participants also suggested that the dashboard should offer a way “*to shift the order around*” by allowing them “*to drag*” different categories. One participant suggested that they want to be able to add and remove certain aspects from the visualizations/ graphs (e.g. “*let's say I don't have some measurements on because I typically don't care about it...*”). Participants wanted to be able to resize certain aspect (e.g. font) of the dashboard and change the style of navigation (e.g. burger vs tabs vs list style menu or horizontal vs vertical navigation).

8.4.2. General Questions and Feedback

FIRST THING NOTICED

Before anything, the participants noticed the traffic-light colour-coding system (“*red, yellow and green...red means danger*”) and understood what it meant immediately (i.e. the messages the colours are conveying about data). In addition, the participants “*figured it [dashboard] was something to do with health*”.

UNFAMILIAR ELEMENTS

The participants did not experience any problems with identifying the elements used; the elements were familiar, thus, allowing them to understand what to do or how to find information.

NAVIGATION DIFFICULTIES

Once the participants “*figured out where the [features/ data they need] is*”, they found the navigation simple and easy to use. One participant mentioned that “*it seems to me, it's easy to navigate around, which is always the main thing... you want to be able to easily navigate*”

DASHBOARD USEFULNESS

The participants found the dashboard useful because “*It covers the majority of the things*” they want to see about their health.

INFORMATION PRESENTATION

The participants enjoyed the way the information was presented; “*there is no information overload and you can focus on a specific category [information]*”; in addition, “*it's (i.e. the presentation) not distracting*”.

HEALTH RISK

The dashboard allows participants to understand their health risk e.g. “*Imagine if your blood pressure's... high.... that's not good... I'd be alarmed more than anything*”. A participant believes “*it should be relatively easy to know which aspects of [their] health are in need of a check-up*”, by using a similar dashboard.

DESIGN ATTRACTIVENESS

One participant thought that *“the aesthetics are a still bit far back but the practicality and everything else is there... unlike most [dashboards] where everything is sort of like hidden... this one is just in your face... it is easy to use”*. Overall, the participants thought the dashboard was *“attractive”*.

OTHER COMMENTS

Participants suggest that a way *“to search... or just to filter”* information on the dashboard is important. One participant did not like *“the lack of symmetry”* (i.e. vertical symmetry) on the overview/ landing screen, therefore, *“since they're vertical columns, maybe make them horizontal”*. Therefore, an option to customize the overview/ landing screen would accommodate all users. The *“last active”* on the overview/ landing screen was confusing to the participants (i.e. it did not articulate the ‘last time’ they used the dashboard). Furthermore, participants suggested a small notification pop-up under the visualizations (graphs) that inform them of a course of action to take when values are abnormal (including context and noteworthy information).

8.4.3. Post Test Questionnaires

8.4.3.1 System Usability Scale (SUS)

Usability is regarded as “the appropriateness to a purpose” of the artifact (Brooke, 1996). The SUS is a reliable and robust ten-item Likert scale (i.e. ranging from strongly disagree (1) to strongly agree (5)) that provides a holistic view of subjective examination of usability. Based on the answers provided by the participants (Table 8.5), the participants found the dashboard design to be consistent with well-integrated functions, easy to learn and use, and they would like to use it frequently. The SUS gave an average score of 80 / 100 (Table 8.6). According to Sauro (2011) and Brooke (1996), a score above 68 is regarded as above average. This further proves that the proposed design guidelines are valuable for developing an effective dashboard (i.e. presents information effectively).

Table 8.5 – System usability scale answer distribution

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q1. I would like to use this dashboard frequently	0%	0%	20%	40%	40%
Q2. I found the dashboard unnecessarily complex	0%	80%	0%	20%	0%
Q3. I thought the dashboard was easy to use	0%	0%	20%	0%	80%
Q4. I would need the support of a technical person to use this dashboard	80%	0%	0%	20%	0%
Q5. I found the various functions in this dashboard were well integrated	0%	0%	60%	40%	0%
Q6. There was too much inconsistency in this	60%	20%	0%	20%	0%
Q7. I learned to use this dashboard very quickly	0%	0%	0%	20%	80%
Q8. This dashboard is very cumbersome to use	60%	0%	20%	20%	0%
Q9. I felt very confident using this dashboard	0%	0%	0%	60%	40%
Q10. I needed to learn a lot of things before I could get going with the dashboard	60%	20%	20%	0%	0%

Table 8.6 – System usability scale score.

Participant	SUS Score
p1	70,0
p2	92,5
p3	90,0
p4	80,0
p5	67,5
Average	80,0

8.4.3.1. User Experience Questionnaire (UEQ)

A UEQ is a 7-point Likert scale – “with the end points not important at all (1) and very important (7)” – of 26 items (i.e. questions). This questionnaire allows educated guesses to be made about areas of the artefact that need improvements. “The UEQ shows a pattern of 6 measured user experience qualities. From this pattern it is possible to make at least some assumptions where to look for improvements” (Schrepp, 2019). These UX qualities include attractiveness (looks enjoyable, pleasant and friendly), efficiency (tasks can be performed quickly and pragmatically), perspicuity (interface is easy to clear, easy to learn and understand, and simple), stimulation (looks exciting, interesting and motivating), dependability (meets expectations and supports the user while performing tasks) and novelty (creatively designed, innovative and inventive) (Schrepp, 2019). A benchmark graph (Figure 8.2) created through the UX Excel-Tool shows how the dashboard rated on the UX qualities.

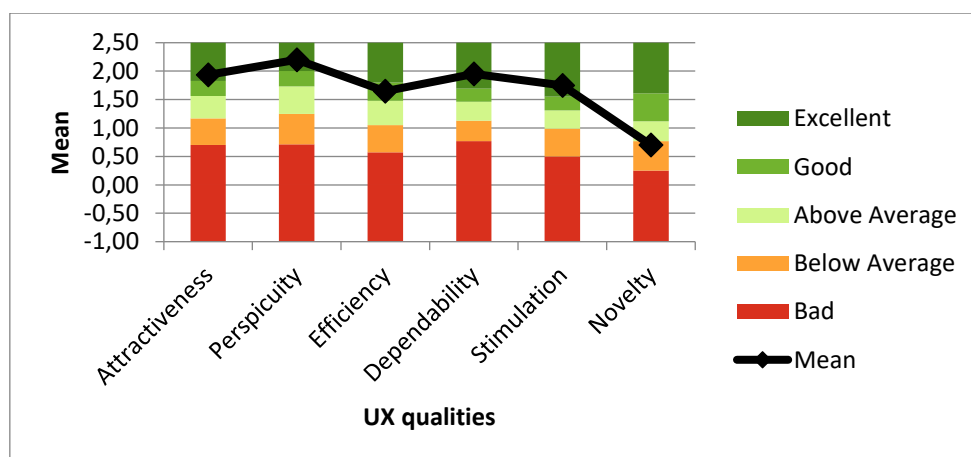


Figure 8.2 – Benchmark graph (results of the user experience questionnaire).

Although the dashboard prototype did not rate well for novelty (inventive), the feedback acquired from UXQ shows that a dashboard designed based on the guidelines will likely be a well-designed dashboard for the prospective users. It is important to note that the dashboard has to be tailored to meet the specific user’s needs; therefore, a number of design iterations have to be conducted in order for the dashboard to fit with the user’s needs (i.e. which is not the goal of this research). Although the prototype was designed for the participants who were part of the focus groups; participants from the usability evaluation (all new) rated it as above average on 5 out of 6 user experience qualities (Figure 8.2); this further reinforces our design guidelines. In other words, the dashboard prototype was interesting and pleasing to the eye,

supported the participants' ease of completing tasks, and easy to learn and understand; however, they did not find the dashboard prototype as innovative. The design of dashboard prototype was relatively effective at presenting the information to the participants of the usability evaluation. Thus, it can be argued that the proposed guidelines may offer valuable insights (i.e. a guide) about designing a dashboard that presents personal health data effectively.

8.5. REFINEMENT OF THE GUIDELINES

Although a medium-fidelity dashboard prototype (i.e. some of the aspects of the guidelines were implicit on the dashboard prototype) for this research, most of the insights were gained from the participants aligned with/ strengthened the information (i.e. from literature and focus groups) that formulated the proposed design guidelines. The usability tests provided a number of noteworthy suggestions that improve (add value to) the proposed set of guidelines. Therefore, this section presents the refined guidelines (Table 8.6) from the proposed set of design guidelines (Table 7.2).

Table 8.7 – Refined areas of the proposed set of design guidelines.

TARGET AUDIENCE
<p>Guideline 1: <u>Provide users with a customizable and/ or personalized interface</u></p> <ul style="list-style-type: none"> ▪ The users' needs, which are often different from the designer, should be understood and catered for in a good dashboard design. The dashboard may provide users with personalized data or features based on their preferences or activity on the dashboard; i.e. provide users with relevant information/ features on the dashboard when activity resumes (when the dashboard is launched). <ul style="list-style-type: none"> ▪ E.g. overview metrics shown in the morning vs the evening. ▪ In addition, the dashboard needs to be customizable to cater for different users and tasks while displaying relevant information required for making decisions. The dashboard should allow them to customize certain features in a manner that fits with their mental-schema (i.e. the way users prefer to view data on the dashboard) <ul style="list-style-type: none"> ▪ E.g. overall colour; navigation style; resizing/ rearrangement information/ features etc.

DATA NEEDS CONTEXT

Guideline 7: Provide users with data context

- Representations should not lead to misinterpretation or false impressions, and they should not distort the “truth” behind the data. Furthermore, data needs to be contextualized in order for the user to understand the meaning of it. Provide users with cues or messages to allow users to be in a better position to understand what is being presented (or not) on the dashboard.
 - E.g. is a metric indicating good or bad - text/ colour for indicating abnormal data; helpful cues or messages such as “data is unavailable”.
- Show correlation between data (visualizations) placed in one view.
 - E.g. how a change in one metric affects another.
- Provide an information panel/ section for users – to show the importance of keeping the metrics aligned with the goal/ target/ benchmark. The information panel should provide more than general information; it should provide the user with a plan of action if and/ or when the metrics are within abnormal ranges (i.e. self-care related information). Pictures along with words are suggested as a means of presenting the information in an easily interpretable manner.
 - E.g. information about what happens when calories burn or what happens when “x” number of calories are lost or self-care measures that need to be considered.
- Providing a small pop-up message (i.e. on/ around the visualizations) is also important in order to provide the user with the appropriate course of action once the visualizations present abnormal values.
 - E.g. a pop up message under a graph when values are critical such as “visit a doctor” or “remember to take your medication”.

CHOOSING THE DISPLAY MEDIA

Guideline 13: Use the appropriate display media (i.e. for the right data type)

- The correct media should be used for displaying data - the media that is suitable to convey the message to the user in an effective manner should be selected.
 - E.g. tables – for individual value identification, text – for explanation and supplementing graphics.

- Display media used for data overview should have the least numeric and text data as possible. They should only provide users with general trends that offer a snapshot of how the user is performing at first glance (quickly and easily).
 - E.g. using traffic light colour-coded gauges without any values.

HIGHLIGHTING IMPORTANT INFORMATION

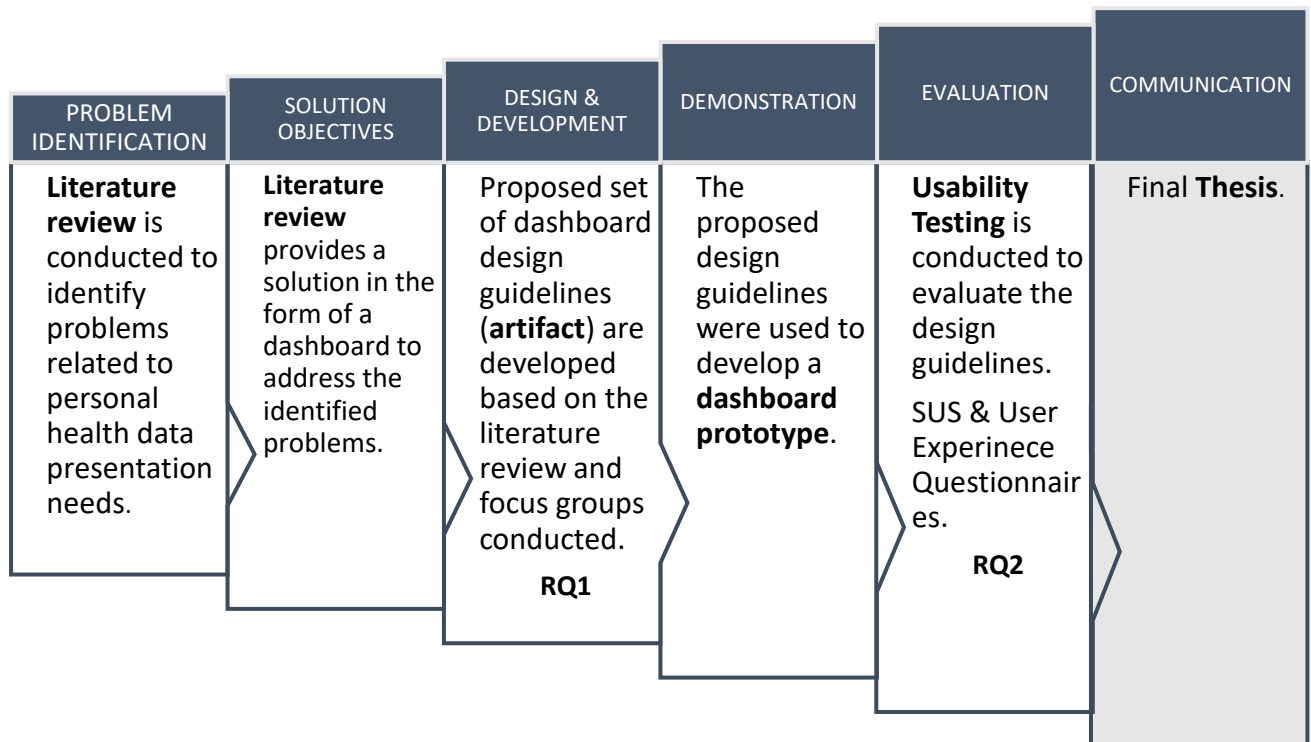
Guideline 16: Highlight important information

- Focus the viewers interest on the main idea instead of how the visual was created; entice the eye to move from one piece of data to another for comparisons, and serve the purpose. Information that needs the immediate attention of the user should be highlighted to ensure it stands out from the rest - this should be done sparingly to ensure it is not overused thus not losing its purpose.
 - E.g. dynamic change of metrics for abnormal values.
- Where possible, provide users with positive notifications/ feedback (rather than negative) and keep the frequency of the notifications at a minimum. The idea is to allow users to be alerted of any values that are sub-optimal while encouraging them to continue using the dashboard for their well-being. The notifications should be kept short (use least amount of words as possible) while highlighting the most important aspect of the message/ notification. Opening more details of the notifications text should be left optional to the user; for instance, a user may be interested in opening/ reading details about critical notifications only.
 - E.g., a short pop up message (with a suggested plan of action) that alerts the user when values are critical.
- A calendar is also valuable to allow users to quickly see the history, present, and upcoming important events/ information to take note of (important).
 - E.g. a calendar that highlights important information on a daily such as “remember to take your blood pressure medication before 9 am after breakfast”

8.6. CONCLUSION

This chapter provided details on how the dashboard prototype was evaluated in order to establish the utility, efficacy and quality of the proposed set of guidelines. The dashboard performed very well in terms of usability/ user experience. Therefore, the proposed set of guidelines were valuable for designing the dashboard prototype. Based on the results, it can be argued that the guidelines are suitable for designing a dashboard that presents data effectively. Furthermore, the evaluation provided new insights (improvements) that are valuable to designing an effective dashboard. The results (discovered insights) were elaborated on and presented to show where they fit into the guidelines (structure). The next chapter presents the achievements and reflects upon the entire research process. The contributions are discussed, as well as future research areas.

CHAPTER 9:
CONCLUSION



In this chapter, the achievement of the research goals will be discussed. This chapter aims to draw conclusions from the research journey. Both theoretical and practical contributions will be discussed, and suggestions for future research will be outlined for further exploration to expand upon the outcomes of this research.

9.1. RESEARCH OVERVIEW

This research aimed at creating a set of dashboard design guidelines that can be used to present personal health data effectively. The rationale for conducting this research is detailed in Chapter 1 (i.e. presenting large volumes of complex personal health data in an easily interpretable manner). To develop the set of guidelines, various aspects (e.g. theories and design features) of visualization and dashboards were reviewed to find the ideal way of designing a dashboard that can present data effectively. A preliminary set of design guidelines was developed and structured based on the categories discovered in the work of Jespersen (2017) (Chapter 4). The health dashboards (Chapter 5) provided domain (i.e. healthcare) specific insights on the idealistic way of tailoring dashboards for health data presentation. To strengthen the learnings (insights) gained from the literature, focus group sessions (Chapter 6) were conducted to further investigate the aspects that are imperative to a dashboard design.

Based on all the insights and valuable information gained, a proposed set of dashboard design guidelines was established (Chapter 7). To evaluate the guidelines, a medium-fidelity dashboard prototype was developed to demonstrate the proposed set of design guidelines. Usability testing (i.e. through the dashboard prototype) was conducted to evaluate the efficacy and utility of the proposed design guidelines (Chapter 8). The success of the demonstrated dashboard prototype, proved the proposed design guidelines as useful for creating a well-designed dashboard. Insights that contributed to the proposed set of guidelines were also discovered. The insights strengthened the guidelines by uncovering certain aspects that were implicit in the literature and focus group sessions; thus improving the quality of the design guidelines. Therefore, a final set of dashboard design guidelines (Section 9.3) was developed that can aid in the creation of dashboards that present personal health data effectively.

9.2. ACHIEVEMENT OF RESEARCH OBJECTIVES

The research had a main objective of developing a set of dashboard design guidelines that can present personal health data effectively. The research objective was reached by addressing the following research questions:

RQ1: What design aspects should be incorporated into the design guidelines for personal health dashboards?

To address RQ1, the literature (Chapter 3, 4, 5) provided the foundation of the visual and functional design aspects that are required to effectively presenting data. Chapter 3 provided insights on how to visualize data effectively. This chapter elaborated on the process of transforming data into an easily interpretable format. In addition, the chapter provided insights on the cognitive process of the interpretation of visually presented data in order for data-driven decision-making. The design aspects that were discovered in this chapter fall under the following areas: personalization, customization, cognitive fit theory, minimizing the data-ink ratio, data context, visual integrity, multiple window layout, symmetry and proportion, details on demand, principles of visual perception, appropriate data medium, graphical excellence, and visualizations should be neat. Chapter 4 & 5 looked at dashboards in general and within the Healthcare domain, in order to uncover insights on good design aspects (Table 4.2. & Table

5.1) that allow data to be presented effectively for ease of interpretation. In addition, focus groups (Chapter 6) were conducted to confirm the relevance of what was discovered in the literature (Chapter 3, 4 & 5); while also eliciting nuanced design aspects (Table 6.3) that were not discovered during the literature review. The design aspects discovered in Chapters 3, 4, 5 & 6 were synthesized to develop the proposed set of guidelines (Chapter 7); the work of Jespersen (2017) (Chapter 4) provided structure for the design guidelines (i.e. allowed the categorization of the design guidelines).

RQ2: How successful are the guidelines at designing an effective personal health dashboard?

The evaluation of the design guidelines (Chapter 8) addressed RQ2. A medium-fidelity dashboard prototype was developed to demonstrate the proposed design guidelines (Chapter 7). The dashboard prototype was evaluated (Chapter 8) to determine the quality and degree to which the guidelines can be used successfully (i.e. for designing a dashboard that presents personal health data effectively). The results (Table 8.6 & Figure 8.2) of the evaluation confirmed the efficacy and utility of the design guidelines. Furthermore, insights were gained (Table 8.7) to improve the quality of the guidelines; thus, resulting into the final set of design guidelines that are presented in Section 9.3.

9.3. FINAL SET OF DESIGN GUIDELINES

This section presents the final set of dashboard design guidelines (Table 9.1) that can inform the development of dashboards for presenting health data effectively.

Table 9.1 – Final dashboard design guidelines.

<p>TARGET AUDIENCE</p> <p>Guideline 1: <u>Provide users with a customizable and/ or personalized interface</u></p> <ul style="list-style-type: none"> ▪ The users’ needs, which are often different from the designer, should be understood and catered for in a good dashboard design. The dashboard may provide users with personalized data or features based on their preferences or activity on the dashboard; i.e. provide users with relevant information/ features on the dashboard when activity resumes (when the dashboard is launched). <ul style="list-style-type: none"> ▪ E.g. overview metrics shown in the morning vs the evening. ▪ In addition, the dashboard needs to be customizable to cater for different users and tasks while displaying relevant information required for making decisions. The dashboard should allow them to customize certain features in a manner that fits with their mental-schema (i.e. the way users prefer to view data on the dashboard) <ul style="list-style-type: none"> ▪ E.g. overall colour; navigation style; resizing/ rearrangement information/ features etc. <p>Guideline 2: <u>Present data to the users in a familiar manner (format)</u></p> <ul style="list-style-type: none"> ▪ It is imperative to make consideration for the way users want the data to be presented. The data should be presented in a manner that users are familiar with – this allows the user to understand the data intuitively. In other words, there should be a fit between the way data is presented (representation) and the user’s mental schema, thus allowing users to understand the data at first glance. <ul style="list-style-type: none"> ▪ E.g. pictographs that utilize familiar (widely used) pictures/ symbols.
<p>SCREEN BOUNDARIES</p> <p>Guideline 3: <u>Provide a single view/ page (and/ or with limited scrolling/ panning)</u></p> <ul style="list-style-type: none"> ▪ The dashboard should present information on a single screen without (limited) scrolling and panning; scrolling through pages makes it difficult for users to view connections between fragmented data. <ul style="list-style-type: none"> ▪ E.g. buttons for dynamic (additional) information.

Guideline 4: Only place related data per dashboard view/ page

- Dashboard elements or data, on a single view or page, should be conceptually and logically related to one another.
 - E.g., show one category (related set) of information per view/ page.
- Fragment data into multiple dashboard views in a manner that ensures data that is related (belongs together) is not separated.
 - E.g. separate page/ view for each category (independent data set).

DISPLAY ESSENTIAL DATA

Guideline 5: Present essential data/ information only on the visualization (charts/ graph etc.)

- Maximize data-ink-ratio – the majority of ink used on graphics should present data/information (i.e. not aesthetics). In other words, the dashboard should present essential information only, for analysis purposes; i.e. embellishments/ decorative visual components should be avoided.
 - E.g. limiting colour usage to adding meaning to data only.

Guideline 6: Minimize cluttering on the dashboard

- The content/ data should be limited to ensure that the dashboard display is not cluttered and does not overload or overwhelm the user with information – split the content/ data into several screens/ views. A five-second rule should be followed to ensure the users find what they are looking for in five seconds or less. In addition, there should only be around 5-9 (7/ +2) objects on the dashboard to minimize clustering.
 - E.g. hiding detailed information; split the content/ data into several screens/ views.

DATA NEEDS CONTEXT

Guideline 7: Provide users with data context

- Representations should not lead to misinterpretation or false impressions, and they should not distort the “truth” behind the data. Furthermore, data needs to be contextualized in order for the user to understand the meaning of it. Provide users with cues or messages to allow users to be in a better position to understand what is being presented (or not) on the dashboard.

- E.g. is a metric indicating good or bad - text/ colour for indicating abnormal data; helpful cues or messages such as “data is unavailable”.
- Show correlation between data (visualizations) placed in one view.
 - E.g. how a change in one metric affects another.
- Provide an information panel/ section for users – to show the importance of keeping the metrics aligned with the goal/ target/ benchmark. The information panel should provide more than general information; it should provide the user with a plan of action if and/ or when the metrics are within abnormal ranges (i.e. self-care related information). Pictures along with words are suggested as a means of presenting the information in an easily interpretable manner.
 - E.g. information about what happens when calories burn or what happens when “x” number of calories are lost or self-care measures that need to be considered.
- Providing a small pop-up message (i.e. on/ around the visualizations) is also important in order to provide the user with the appropriate course of action once the visualizations present abnormal values.
 - E.g. a pop up message under a graph when values are critical such as “visit a doctor” or “remember to take your medication”.

LAYOUT

Guideline 8: Place important information (elements) towards the top and left-hand side (where it’s easily viewed/ accessible)

- Important data should be placed towards the top and left hand-side of the dashboard display; most people read from top to bottom and left to right therefore their eyes are automatically fixed at the top left corner first. The top and / or left-hand side should show noteworthy (newsworthy) information, the middle should present important information, and the bottom and/ or right-hand side should show general information.
 - E.g. show noteworthy (newsworthy/ critical) charts at the top of the screen.

Guideline 9: Follow the principles of visual perception

- Keep the principles of visual perception in mind when organizing elements or data on the dashboard – to identify elements that are enhancements/ pollutants on the dashboard.

- E.g. placing related charts side-by-side for comparisons.

Guideline 10: Use multiple windows to present independent data

- Present data/ visualizations that are independent to one another in different windows.
 - E.g. showing all critical graphs on one page/ view.
- A maximum of six windows is recommended to ensure that the display is effective – to avoid overwhelming the user with a large number of windows. Uniform sized windows are recommended to ensure the visualizations are given equal importance unless priority has to be given to a single window.
 - E.g. data panels to group related visualizations

Guideline 11: Provide a summary (overview) of data first – information-seeking approach

- Provide users with an overview of information first - a consolidated overview of information to allow users to identify the information that needs their immediate attention. Allow the users to zoom, search and/ or filter the information - provide enough information to allow the user to determine whether further investigation is required. Lastly, provide the users with the ability to get details on demand i.e. drill down into certain (more detailed) information of interest.
 - E.g. summarized information with controls (buttons) for showing more details.

Guideline 12: Place the navigation cluster (list/ tabs/ pictograms) towards the left-hand side

- Provide the users with the ability to navigate through the dashboard easily. A simple navigation “bar” should be placed towards the left-hand side of the dashboard (*Users preferred icons/ pictograms (graphics) with labels for navigation options/ categories; most ideal for small screens (devices). If need be, a list-style navigation may be used for larger screens (devices). However, the navigation design entirely depends on the type of device.*)
 - E.g. icon-based navigation tabs that represent a data-category option.

CHOOSING THE DISPLAY MEDIA

Guideline 13: Use the appropriate display media (i.e. for the right data type)

- The correct media should be used for displaying data - the media that is suitable to convey the message to the user in an effective manner should be selected.
 - E.g. tables – for individual value identification, text – for explanation and supplementing graphics.
- Display media used for data overview should have the least numeric and text data as possible. They should only provide users with general trends that offer a snapshot of how the user is performing at first glance (quickly and easily).
 - E.g. using traffic light colour-coded gauges without any values.

Guideline 14: Determine if the dashboard will push information to the user or draw the user to view the information

- The dashboard can “push” information that is important through drawing the user’s attention to unforeseen or unexpected situations.
 - E.g. notification pop-up to grab the user’s attention.
- The dashboard can be used to gain specific information when the user needs it.
 - E.g. offering ways for exploring, filtering, or searching visualizations when needed.

DISPLAY MEDIA DESIGN

Guideline 15: Use uniform display media design

- The display medium should have a similar look across all displays/ windows for a better user experience. Standards for icons and labels that are familiar to the user should be selected to convey data to the user effectively.
 - E.g. widely used icons and labels that are familiar to the user should be consistently utilized across all view/ pages.

HIGHLIGHTING IMPORTANT INFORMATION

Guideline 16: Highlight important information

- Focus the viewer’s interest on the main idea instead of how the visual was created; entice the eye to move from one piece of data to another for comparisons, and serve the purpose. Information that needs the immediate attention of the user should be

highlighted to ensure it stands out from the rest - this should be done sparingly to ensure it is not overused thus not losing its purpose.

- E.g. dynamic change of metrics for abnormal values.
- Where possible, provide users with positive notifications/ feedback (rather than negative) and keep the frequency of the notifications at a minimum. The idea is to allow users to be alerted of any values that are sub-optimal while encouraging them to continue using the dashboard for their well-being. The notifications should be kept short (use least amount of words as possible) while highlighting the most important aspect of the message/ notification. Opening more details of the notifications text should be left optional to the user; for instance, a user may be interested in opening/ reading details about critical notifications only.
 - E.g., a short pop up message (with a suggested plan of action) that alerts the user when values are critical.
- A calendar is also valuable to allow users to quickly see the history, present, and upcoming important events/ information to take note of (important).
 - E.g. a calendar that highlights important information on a daily such as “remember to take your blood pressure medication before 9 am after breakfast”.

Guideline 17: Use a salient benchmark to indicate to the users how far they are from reaching a desirable target.

- Provide a benchmark for each visualization (i.e. graph, chart etc.) to assist the user in interpreting the risk being presented by the visualization. This allows the user to quickly/ almost immediately realise they have to make changes/ take actions towards meeting the ideal target (such as calling a doctor, taking medication or increasing daily activity).
 - E.g. a horizontal/ vertical line (on the visualization) that represents an important goal/threshold.

COLOUR PALETTE

Guideline 18: Use appropriate colours for readability and to enhance the data (for interpretability)

- Colour (2-3 colours and gradients of the same colour) should be used to clarify content. Due to individual differences, alternatives (i.e. colour) should be given to the users who prefer not to use “defaults”; while still drawing the attention to the important information. In addition, rules of colour should be kept in mind when selecting colours for the dashboard.
 - E.g. traffic- light colour coding system (red, orange/ yellow, and green) to indicate “progress”/ data changes.

MAKE THE DASHBOARD ATTRACTIVE

Guideline 19: Design an attractive dashboard

- A “minimalist design” should be the goal. In other words, the dashboard should be neat and clean through good visualization design and dashboard theme choices; however, data clarity (interpretability) is still more important.
 - E.g. using material or flat designs, and high-resolution images & text etc.

9.4. RESEARCH CONTRIBUTION

9.4.1. Theoretical

Design science research aims at contributing through the development of a relevant artifact. This research utilized design science research approach (Figure 2.5) to make a contribution to the knowledge base through the development of dashboard design guidelines that can be used to create dashboards that present personal health data effectively (Hevner et al., 2004; Hevner & Chatterjee, 2010). The research was inclined towards the adaptation quadrant (Figure 2.3) of the knowledge contribution framework (Gregor & Hevner, 2013b; Vaishnavi et al., 2019). In other words, it aimed at adapting known dashboard (i.e. including visualization) design aspects in order to solve problems related to presenting personal health data in an easily interpretable manner. The dashboard design guidelines were based on synthesized design aspects uncovered from the literature and focus groups, however, they were tailored (i.e. non-trivial adaptation) to address the identified issues related to personal health data presentation. Furthermore, there is limited research on dashboard designs; therefore, the design guidelines make a significant effort to contribute to the knowledge base. These holistic set of dashboard design guidelines can be utilized as a foundation (i.e. iterations are imperative to ensure that

the designs meet specific user needs) for designing dashboards for different personal health data presentation needs (Meidani et al., 2021).

9.4.2. Practical

The proposed set of design guidelines (Chapter 7) was used to create a medium-fidelity dashboard prototype that was examined (Chapter 8) to see the efficacy and utility of the guidelines. The dashboard prototype presented personal health data effectively. Section 9.3 presents the final set of dashboard design guidelines that is based on the proposed design guidelines (Chapter 7) and improvements discovered from the dashboard prototyped evaluation (Chapter 8). The final set of design guidelines (Table 9.1) outlines how the dashboard can be designed including examples on how the guidelines can be put into practice. Using an extract from Table 9.1, the text highlighted in yellow (Table 9.2) provides instructions on how the guideline should be applied; and the text highlighted in green (Table 9.2) presents an example of how the guideline can be applied. Following these design guidelines (Table 9.1) will likely result into, arguably, a well-designed dashboard that presents personal health data effectively.

Table 9.2 – Excerpt from the final set of guidelines (Table 9.1).

COLOUR PALETTE
<p>Guideline 18: <u>Use appropriate colours for readability and to enhance the data (for interpretability)</u></p> <ul style="list-style-type: none"> ▪ Colour (2-3 colours and gradients of the same colour) should be used to clarify content. Due to individual differences, alternatives (i.e. colour) should be given to the users who prefer not to use “defaults”; while still drawing the attention to the important information. In addition, rules of colour should be kept in mind when selecting colours for the dashboard. <ul style="list-style-type: none"> ▪ E.g. traffic- light colour coding system (red, orange/ yellow, and green) to indicate “progress”/ data changes.

9.5. LIMITATIONS

This research was conducted during a world pandemic (“COVID-19”); therefore, accessibility to participants was difficult (e.g. reliant on virtual focus groups). Access to a larger population sample that represents a wider range of backgrounds was not possible; only a limited sample size of eight participants for the Focus Groups (four for each session) (Chapter 6), and five participants for Usability Testing (Chapter 8) was used. However, the sample sizes aligned with the recommendations made by Nielsen (2000), Rabiee (2004), and Bastien (2010). Although, the sample sizes were enough to provide valuable insights, larger sample sizes may have ensured that other design aspects were discovered.

Although there is a paucity of literature on personal health dashboards, this research only focused on the design aspects (i.e. front-end related aspects) of dashboards. In other words, aspects such as flow of data between the databases (i.e. information repositories) and the dashboard, the operational aspects (e.g. hardware, software etc.), security (e.g. authentication), and performance aspects (e.g. response time); are not covered by this research.

9.6. FUTURE RESEARCH

An evaluation (application) of these design guidelines in more specific use cases such as diabetes and/ or obesity self-care and self-management, could allow insights to be discovered on the efficacy and utility; thus strengthening and improving the quality of the design guidelines. Furthermore, research on dashboard designs (i.e. interfaces) that allow users to input their personal health data directly into the dashboard could prove useful for the set of design guidelines presented by this research.

9.7. CONCLUDING REMARKS

This research aimed at developing dashboard design guidelines in order to address the problems related to individuals interpreting large volumes of complex personal health data. These design guidelines were based on design aspects discovered from the literature, focus groups, and usability testing. Thus, allowing a holistic set of design guidelines to be created for tailoring dashboard designs that support personal health data interpretability. To realise this objective,

Design Science Research Methodology guided the process (i.e. provided structure) of this research in order to ensure the efficacy, utility and quality of the design guidelines. The research questions were developed to guide this research and addressed to provide solutions for problems discovered (i.e. easily interpretable presentation of large volumes of complex personal health data). Rigor was applied to ensure that the design guidelines are suitable for developing dashboards for individuals who want to view their personal health data in an easily interpretable manner. Although the dashboard design guidelines were aimed at personal health data presentation, the guidelines have qualities (i.e. design aspects) that can be generalized to other fields or domains.

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Appendix A. Informed consent form



PARTICIPANT INFORMED CONSENT INFORMED CONSENT DECLARATION (Participant)

Project Title: Design guidelines for personal health overview dashboards.

Chabana Chabana from the Department of *Information systems*, Rhodes University has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. This research requires participants who are of 18 years and above.
2. The purpose of the research project is to develop a set of design guidelines that can be used to create a personal health overview dashboard.
3. The Rhodes University has given ethical clearance to this research project and I have seen/ may request to see the clearance certificate.
4. By participating in this research project I will be contributing towards producing a set of guidelines that can be used to develop personal health overview dashboards to reduce the cognitive load experienced by patients who are often struggle to understand their personal health data.
5. I will participate in the project by providing the facilitator with relevant information and/ or feedback through-out the requirements gathering phase; and user testing phase for evaluating the dashboard prototype.
6. My participation is entirely voluntary and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.
7. I will not be compensated for participating in the research.

8. The researcher intends publishing the research results in the form of a Master’s thesis and conference/journal articles. However, confidentiality and anonymity of records will be maintained and that my name and identity will not be revealed to anyone who has not been involved in the conduct of the research.
9. I will receive feedback in the form of a final Master’s thesis regarding the results obtained during the study.
10. Any further questions that I might have concerning the research or my participation will be answered by Chabana Chabana (+27610500921 or chabanac@gmail.com)
11. By signing this informed consent declaration I am not waiving any legal claims, rights or remedies.
12. A copy of this informed consent declaration will be given to me, and the original will be kept on record.
13. I agree to Chabana Chabana's request to make use of video and/or voice recordings as part of this research study

I, have read the above information / confirm that the above information has been explained to me in a language that I understand, and I am aware of this document’s contents. I have asked all questions that I wished to ask and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above-mentioned project.

.....

Participants signature

Witness

Date

Rhodes University, Research Office, Ethics

Ethics Coordinator: ethics-committee@ru.ac.za

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Appendix B. System Usability Scale Questionnaire

1. I would like to use this dashboard frequently

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

2. I found the dashboard unnecessarily complex

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

3. I thought the dashboard was easy to use

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

4. I would need the support of a technical person to use this dashboard

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

5. I found the various functions in this dashboard were well integrated

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

6. There was too much inconsistency in this dashboard

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

7. I learned to use this dashboard very quickly

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

8. This dashboard is very cumbersome to use

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

9. I felt very confident using this dashboard

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

10. I needed to learn a lot of things before I could get going with the dashboard

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Appendix C. User Experience Questionnaire

annoying	○ ○ ○ ○ ○ ○ ○ ○	enjoyable
not understandable	○ ○ ○ ○ ○ ○ ○ ○	understandable
creative	○ ○ ○ ○ ○ ○ ○ ○	dull
easy to learn	○ ○ ○ ○ ○ ○ ○ ○	difficult to learn
valuable	○ ○ ○ ○ ○ ○ ○ ○	inferior
boring	○ ○ ○ ○ ○ ○ ○ ○	exciting
not interesting	○ ○ ○ ○ ○ ○ ○ ○	interesting
unpredictable	○ ○ ○ ○ ○ ○ ○ ○	predictable
fast	○ ○ ○ ○ ○ ○ ○ ○	slow
inventive	○ ○ ○ ○ ○ ○ ○ ○	conventional
obstructive	○ ○ ○ ○ ○ ○ ○ ○	supportive
good	○ ○ ○ ○ ○ ○ ○ ○	bad
complicated	○ ○ ○ ○ ○ ○ ○ ○	easy
unlikable	○ ○ ○ ○ ○ ○ ○ ○	pleasing
usual	○ ○ ○ ○ ○ ○ ○ ○	leading edge
unpleasant	○ ○ ○ ○ ○ ○ ○ ○	pleasant
secure	○ ○ ○ ○ ○ ○ ○ ○	not secure
motivating	○ ○ ○ ○ ○ ○ ○ ○	demotivating
meets expectations	○ ○ ○ ○ ○ ○ ○ ○	does not meet expectations
inefficient	○ ○ ○ ○ ○ ○ ○ ○	efficient
clear	○ ○ ○ ○ ○ ○ ○ ○	confusing
impractical	○ ○ ○ ○ ○ ○ ○ ○	practical
organized	○ ○ ○ ○ ○ ○ ○ ○	cluttered
attractive	○ ○ ○ ○ ○ ○ ○ ○	unattractive
friendly	○ ○ ○ ○ ○ ○ ○ ○	unfriendly
conservative	○ ○ ○ ○ ○ ○ ○ ○	innovative