USABILITY GUIDELINES INFORMING KNOWLEDGE VISUALISATION IN DEMONSTRATING LEARNERS' KNOWLEDGE ACQUISITION

By

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I declare that the above dissertation is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

I further declare that I submitted the thesis to originality checking software. The result summary is attached. All sources used or quoted have been indicated and acknowledged by means of complete references.

_____________ ____January 2019____

SIGNATURE DATE

Acknowledgement

My unreserved acknowledgment to the Lord God Almighty for His never-ending grace.

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Abstract

There is growing evidence that knowledge co-creation and interactivity during learning interventions aid knowledge acquisition and knowledge transfer. However, learners have mostly been passive consumers and not co-creators of the knowledge visualisation aids created by teachers and instructional designers. As such, knowledge visualisation has been underutilised for allowing learners to construct, demonstrate and share what they have learned. The dearth of appropriate guidelines for the use of knowledge visualisation for teaching and learning is an obstacle to using knowledge visualisation in teaching and learning. This provides a rationale for this study, which aims to investigate usability-based knowledge visualisation guidelines for teaching and learning. The application context is that of Science teaching for high school learners in the Gauteng province of South Africa.

Following a design-based research methodology, an artefact of usability-based knowledge visualisation guidelines was created. The artefact was evaluated by testing learners' conformity to the visualisation guidelines. Qualitative and quantitative data was captured using questionnaires, interviews and observations.

The findings indicate that the guidelines considered in this study had various degrees of impact on the visualisations produced by learners. While some made noticeable impact, for others it could be considered negligible. Within the context of high school learning, these results justify the prioritisation of usability-based knowledge visualisation guidelines.

Integrating Human Computer Interaction usability principles and knowledge visualisation guidelines to create usability-based knowledge visualisation guidelines provide a novel theoretical contribution upon which scientific knowledge visualisation can be expanded.

Keywords

Human Computer Interaction, Design-based research, Visualisation, Information visualisation, Knowledge visualisation, Knowledge visualisation framework, Mobile devices, Mobile application, Usability-based knowledge visualisation guidelines, Usability principles

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Publication from this research

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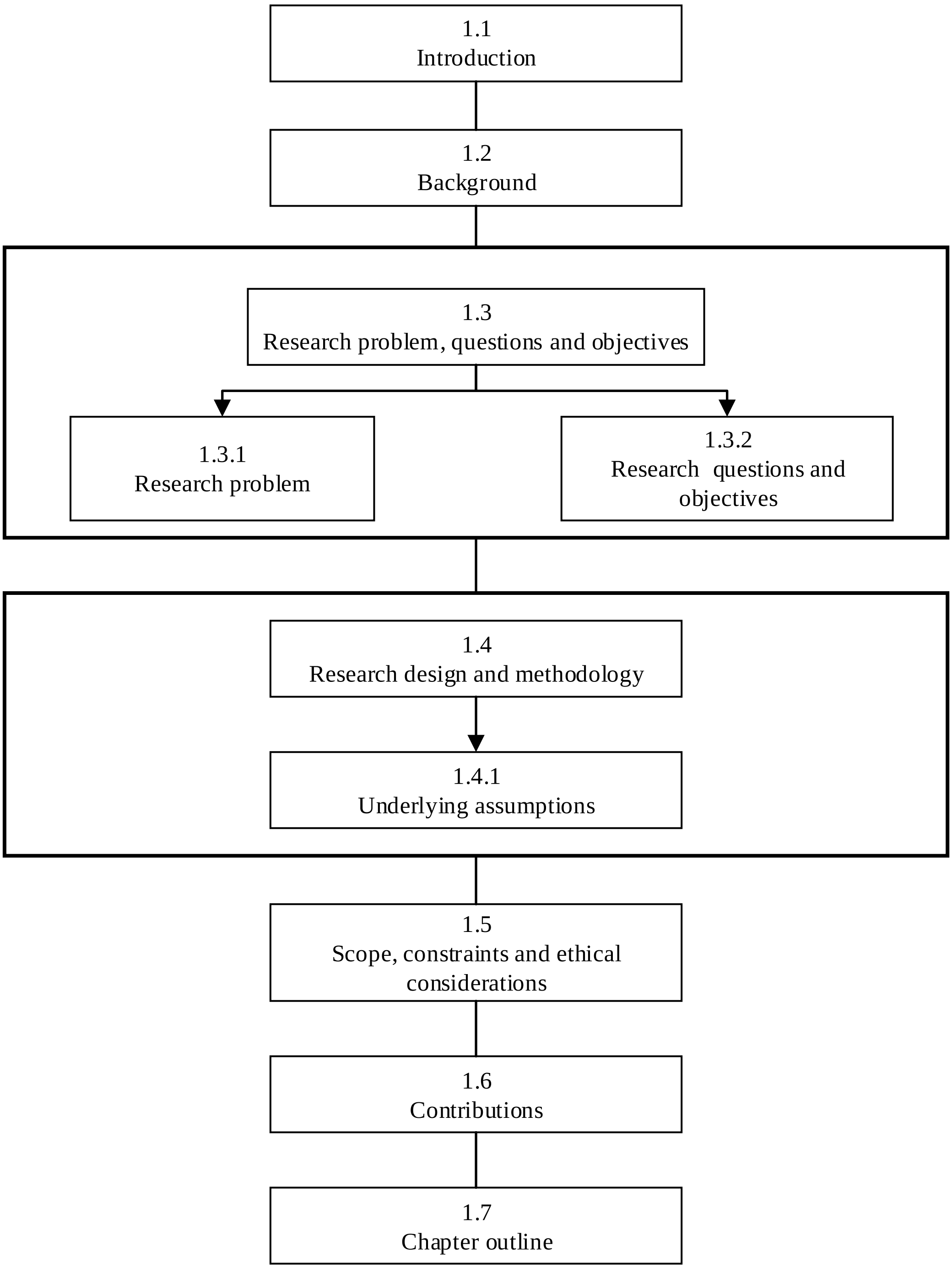
List of abbreviations and acronyms

DBR	Design-based research
HCI	Human Computer Interaction
KV	Knowledge visualisation
SLR	Systematic Literature review
STEM	Science, Technology, Education and Mathematics

Map of Chapter 1 (Introduction)



Chapter 1 Introduction

1.1 Introduction

This research explores the use of knowledge visualisation (KV) by high school science learners by utilizing digital devices to aid knowledge internalisation and transfer in a way that supports the teacher in assessing the student's understanding. It examines knowledge and information visualisation at the intersection of Human Computer Interaction (HCI), as a sub-discipline of Computer Science and Education. KV can simply be defined as the use of images to aid knowledge creation and transfer (Eppler, 2011; Yusoff, Katmon, Ahmad, & Miswan, 2013), while information visualisation uses visual representations to abstract data so as to reveal meaningful patterns (Sindiy, Litomisky, Davidoff, & Dekens, 2013). To this end, *representation* and *interaction* which forms the main component of visualisation (Elmqvist, Vande Moere, Jetter, Cernea, Reiterer & Jankun-Kelly, 2011; Saket, Srinivasan, Ragan, & Endert, 2017) coincide with core values of HCI. This therefore positions the study in the field of HCI. The similarities and differences between KV and information visualisation, together with their relationship with HCI is elaborated in section 3.3 and 3.4. Further, the study proposes that by learners creating their own visual representation about a specific subject, they can achieve deeper understanding of their learning material (Ainsworth, Prain & Tytker, 2011).

In this introductory chapter, the background for the study is provided in section 1.2. Section 1.3 elaborates on the research problem, research questions and objectives. The research design and methodology are described in section 1.4, and section 1.5 refers to the scope, constraints and ethical considerations that guided the study. Section 1.6 provides an overview of the chapters comprising the study, while the significance of the study's outcomes, results and contributions are discussed in section 1.7.

1.2 Background

An important role of a teacher is to aid the transfer of knowledge to students in a way that is meaningful and understandable (Zhang, He, Xie & Wang, 2008; Stürmer, Könings & Seidel, 2013). The teacher uses teaching materials such as textbooks, lecture notes, multimedia resources, amongst others, to function in this role. Teachers also employ specific strategies to support knowledge creation and transfer, and one of these strategies is KV. Visualisation entails using images to communicate data (Munzner, 2009). It should be noted, however, that such visual images for teaching and learning are often created by teachers, educational, learning and instructional designers with little or no input from learners (Yusoff, Katmon, Ahmad & Miswan, 2013; Van Biljon & Renaud, 2015a). According to Wright (2012), learners should be made co-creators of their learning experience rather than simply making education available for their consumption. In addition, there is evidence that co-creation and interactivity aids knowledge acquisition and cognitive skills (Sims, 1997; Gros & López, 2016) and, therefore, warrants further investigation as it relates to KV by learners.

One of the processes of transferring knowledge is through internalisation (Rumanti & Hidayat, 2014), which is explained as the process of facilitating the transformation of explicit knowledge into tacit knowledge, whereby the focus is on the learners engaging with the knowledge, rather than the teacher sharing his knowledge (Kale & Singh, 1999). The learners' ability to acquire, assimilate and sort the knowledge plays an important role in their learning process as learners are unique in the manner they absorb, process and store information. To more easily internalise knowledge, learners have to engage in its creation (Wright, 2012). Given the growing emphasis on the use of KV for teaching and learning to improve performance and learning, learners ought to be allowed the opportunity to co-create the visual images that make this possible. According to Ainsworth, Prain and Tytker (2011), when learners are encouraged to visualise, it can help: enhance engagement; deepen learners' understanding; develop reasoning in science; enhance learning strategy; and enhance communication.

This dissertation argues that KV has the potential for demonstrating students' tacit learning since it supports the identification of objects and the relationships among them. Literature has shown various authors proposing several visualisation guidelines based on personal experiences and specific goals (Forsell & Johansson, 2010; Begoli & Horey, 2012). There is, however, a need to develop context specific KV (Van Biljon & Renaud, 2015b) and this study investigates usability principles as a scientific point of departure. The research is guided by the design-based research methodology (DBR): an educational variation of design research which focuses on design and iterative testing, to generate pragmatic and generalizable design principles in real-world settings (Wang & Hannafin, 2005; De Villiers & Harpur, 2013; Wang, Hsu, Reeves & Coster, 2014; Anderson & Shattuck, 2016).

1.3 Research problem, questions and objectives

The research problem, the research's aim, the research questions and research objectives of this study are described below.

1.3.1 Research problem

During the practice of teaching and learning, there is a high tendency to provide too much information to learners which may lead to disorientation and cognitive overload (Aidi, 2009; Leppink, Van Gog, Paas & Sweller, 2015). KV can offer cognitive benefits such as: raise awareness and provide focus for knowledge creation and transfer; improve memorability; and reveal previously hidden connections that lead to sudden insights (Eppler & Burkhard, 2004). Keller and Tergan (2005) also suggest that visualisation of knowledge enhances cognitive processing because visual pattern matching can be faster and more effective than queries to assess data in the brain. In addition, research has shown that visual representation improves knowledge acquisition when compared to textual view (Yuan & Xin, 2008) and thus KV has the potential for knowledge transfer (Burkhard, 2004; Nonaka, 2008). KV is used by teachers, educational, learning and instructional designers to create teaching and learning materials for learners but it is underutilised for allowing learners to construct, demonstrate and share what they have learned. Nonetheless, it must be acknowledged that some pitfalls have been encountered during the utilisation of KV (Huang, Eades & Hong, 2009; Pieters, Wedel & Batra, 2010; Baumeister & Freiberg, 2011; Liu & Li, 2012; Yayavaram & Chen, 2013). As such, teachers need guidelines on how to construct and evaluate KV appropriately. This research aims to address that problem by developing and evaluating usability-based knowledge visualisation guidelines that can contribute to making learners active participants in their learning experience. In this study the basic elements will be expressed as principles, and these principles will later be used to formulate the guidelines.

1.3.2 Research questions and objectives

In response to the research problem identified in the previous section, the main research question for this study is:

RQ: How can usability principles inform knowledge visualisation guidelines to support knowledge transfer in high-school science education?

The table below highlights the sub-research questions investigated to facilitate the main research question, together with the objectives of the research:

Table 1.1: Research questions and objectives

Research Questions		Research Objectives	Research strategy
RQ_1:	What are the existing knowledge visualisation principles for teaching and learning?	**RO_1:** To identify knowledge visualisation principles applicable to teaching and learning from literature	Literature review/Usability evaluation
RQ_2:	Which usability principles are relevant to knowledge visualisation?	**$RO_{2.1}$:** To identify usability principles relevant to knowledge visualisation **$RO_{2.2}$:** To identify usability principles relevant for the selection of visualisation tools	Literature review
RQ_3:	How can usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education be evaluated?	**RO_3:** To investigate how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation in a way that the teacher can assess the quality of knowledge that has been transferred to learners	Evaluation of usability-based knowledge visualisation guidelines

While acknowledging the multi-dimensional and inter-related nature of pedagogy, this study focuses on: (a) identifying KV principles applicable to teaching and learning; (b) identifying usability principles which are applicable to KV and relevant for the selection of visualisation tools as stated in Table 1.1; and (c) investigating the use of usability-based knowledge visualisation guidelines for teaching and learning.

These research questions and objectives will be investigated by following the research methodology discussed in section 1.4.

1.4 Research design and methodology

Action research and design-based research (DBR) were considered as possible research methodologies for this study as they both identify with real world situations (Oates 2006). In addition, Anderson and Shattuck (2016) explain that the two research approaches are comprised of similar epistemological, ontological, and methodological ideas. However, due to some of the limitations inherent in action research, it was not conducive. As such, the research design adopted for this study is DBR for the following reasons:

- Action research is normally centred around an individual while in DBR, the participants can either be the subject or the object of the research (McNiff & Whitehead, 2010, 2011; Anderson & Shattuck, 2016; Wood & Hendricks, 2017).
- In a DBR, design is necessary, while in action research, design is a possibility (Bakker & Eerde, 2015).

- DBR has instructional theory as the focal point while in action research, the focus is on action and the improvement of a situation (Bakker & Eerde, 2015).

A brief overview of the DBR and methodology is offered in this section while a detailed explanation can be found in section 2.3.

DBR can be defined as a systematic but flexible methodological paradigm directed at improving educational practices while making both practical and theoretical contributions (Wang & Hannafin, 2005; Schoeman, 2015). Schoeman (2015) further explains that the practical contribution is grounded in using existing scientific technology, for example, mobile technologies, in solving a problem in our natural world such as teaching and learning. Its theoretical contribution is created by improving existing design theories and principles. DBR is referred to as the educational variation of design research, and is often used in computing education research (CER) (Cooper, Grover, Guzdial & Simon, 2014). Wang and Hannafin (2005) identify five characteristics of DBR which are: (a) pragmatic (i.e. design-oriented and intervention-oriented); (b) grounded in theory and research; (c) interactive, iterative and flexible; (d) integrative; and (e) contextual. The relationship among these characteristics and their position in this study can be found in Table 2.4.

Figure 1.1 shows a compressed research process flowchart for this study. To answer the research question, this study was carried out in two steps; firstly, to evaluate digital visualisation tools using usability principles (Chapter 4) and secondly, to evaluate usability-based knowledge visualisation guidelines during knowledge transfer in high-school science education (Chapter 5). The participants involved in the usability-based knowledge visualisation guidelines evaluation were a group of high school science learners who were required to create visualisation models (using KV tools installed on digital technologies). The evaluation included a test to explain the process of a rocket launch using images. Learners were then exposed to KV guidelines and the initial images produced were updated to accommodate these principles. The goal of the exercise was to investigate the effect of each guideline on the images produced by the learners and how the guidelines helped improve their knowledge representation for demonstrating their knowledge acquisition.

The databases used for the literature searches were IEEE Xplore, Google Scholar, Scopus, Springer and ACM. These databases contain both indexes and abstracts and they provide full-text scholarly literature (i.e. journals, conference proceedings, books etc.) that cut across a wide range of disciplines, specifically in the field of computer science. The searches were carried out between February 2016 and June 2018 and span only English papers published within the last 7 years, although some seminal publications published outside the specified period were consulted.

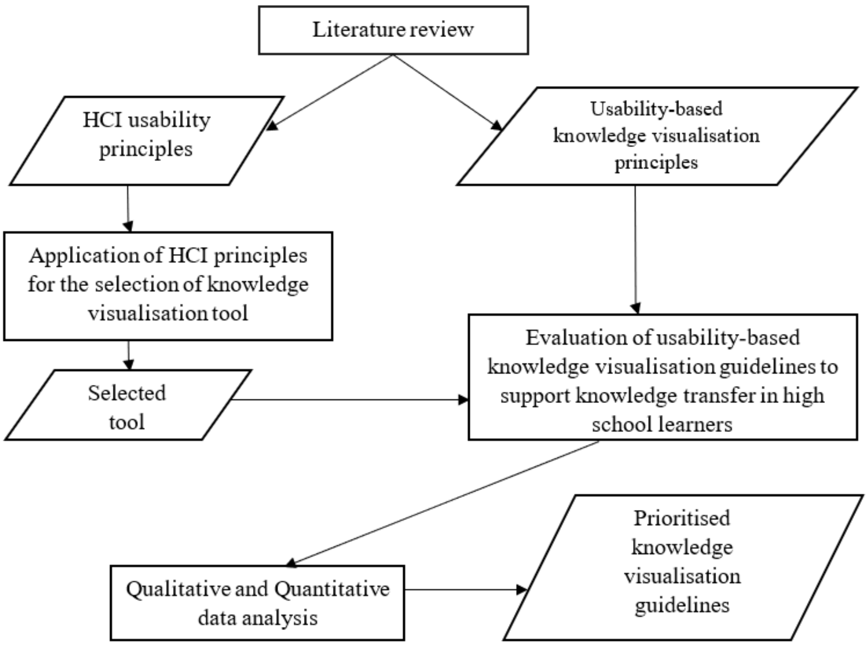


Figure 1.1: Research process flowchart extract

1.4.1 Underlying assumptions

It was assumed that knowledge internalisation can be perceived (measured) by the learners' performance in a test.

1.5. Scope, constraints and ethical considerations

The scope of this research project is limited to the evaluation of usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education. The participants were high school science learners in Gauteng province, South Africa, usability experts, a high-school science teacher and the researcher. The choice to only focus on high-school science learners was initially made to develop a model which could be extended to STEM education (*acronym for Science, Technology, Education and Mathematics*). But due to time, cost and access constraint, only high-school science learners in Gauteng, were involved in the research.

This study used human participants and thus, ethical clearance was obtained as discussed in section 2.3.6.

1.6 Contributions

This dissertation investigated how usability-based knowledge visualisation guidelines could provide support in improving knowledge acquisition and transfer amongst high school science learners.

The theoretical contributions of this study include the following:

- Identifying KV principles applicable to teaching and learning.
- Identifying HCI usability principles relevant for the selection of KV tools.
- Integrating HCI usability principles and KV guidelines to create usability-based knowledge visualisation guidelines for teaching and learning.

These principles and guidelines are supported by evidence from literature and validated by the researcher as explained in chapters 4 and 5. The findings indicate that most of the principles considered in this study had various degrees of impact on the images produced by learners. While some had a significant impact, it could be considered negligible in others. This, therefore, calls for prioritisation of the KV guidelines, for the context of high school science learners.

The main methodological contribution of this study is the application of concepts from Human Computer Interaction and information visualisation for the purpose of studying KV guidelines in teaching and learning. Another methodological contribution lies in the experience gained through the application of the design-based approach and techniques applied for both quantitative and qualitative data collections. Lessons gained from these techniques may be useful for other studies on the use of usability-based knowledge visualisation guidelines in other fields.

The practical contributions made by this study consist of the selection of a suitable KV tool and the prioritisation of KV guidelines in the context of high school science learners. The process for the former consisted of a usability test while the latter was tested through two implementation cycles. Implementing the research indicated that usability-based knowledge visualisation guidelines can be utilised for its intended purpose. Another practical contribution is the usefulness of the KV guidelines for teachers. Knowledge transfer was measured by comparing the before and after marks of learners during the usability-based knowledge visualisation guidelines evaluation.

In addition, this study describes and demonstrates a method of using KV to improve knowledge acquisition. This method can be adopted for use among high school science learners in South Africa in order to harness the real-life benefits of becoming co-creators of knowledge.

1.7 Chapter outline

The layout of each chapter (Table 1.2) is such that the research questions and objectives stated in section 1.3.2 are sequentially addressed.

Chapter 1 provides an overview of the research topic, both in a general context and, more specifically, in light of South African high school science learners in Gauteng. The background, research objectives and questions, research design and methodology, scope, constraints, contribution as well as ethical clearance are also discussed.

In Chapter 2, the research design methodology used for this study is discussed and it provides the background to the philosophical stance adopted for the research. A literature review, can be regarded as a data collection tool (Onwuegbuzie & Frels, 2016). The literature review in Chapter 3 as the data collection tool is integral to the research methodology for this study, and its role is therefore, explained in the next chapter.

Table 1.2: Chapter outline in relation to research questions and objectives

Chapter	Chapter Name	DBR Phases	Research Objective	Research Question
1	Introduction	-		
2	Research design and methodology	Development of solution, outline artefacts	$RO_{1,2.1-2.2,3}$	$RQ_{1,2,3}$
3	Literature review	Problem identification	$RO_{1, 2.1-2.2}$	$RQ_{1,2}$
4	Usability evaluation of knowledge visualisation tools	Define requirements	$RO_{2.1-2.2}$	RQ_{2}
5	Evaluation of usability-based knowledge visualisation guidelines	Design, develop and evaluate artefacts	$RO_{1,3}$	$RQ_{1,3}$
6	Conclusion	-	-	-

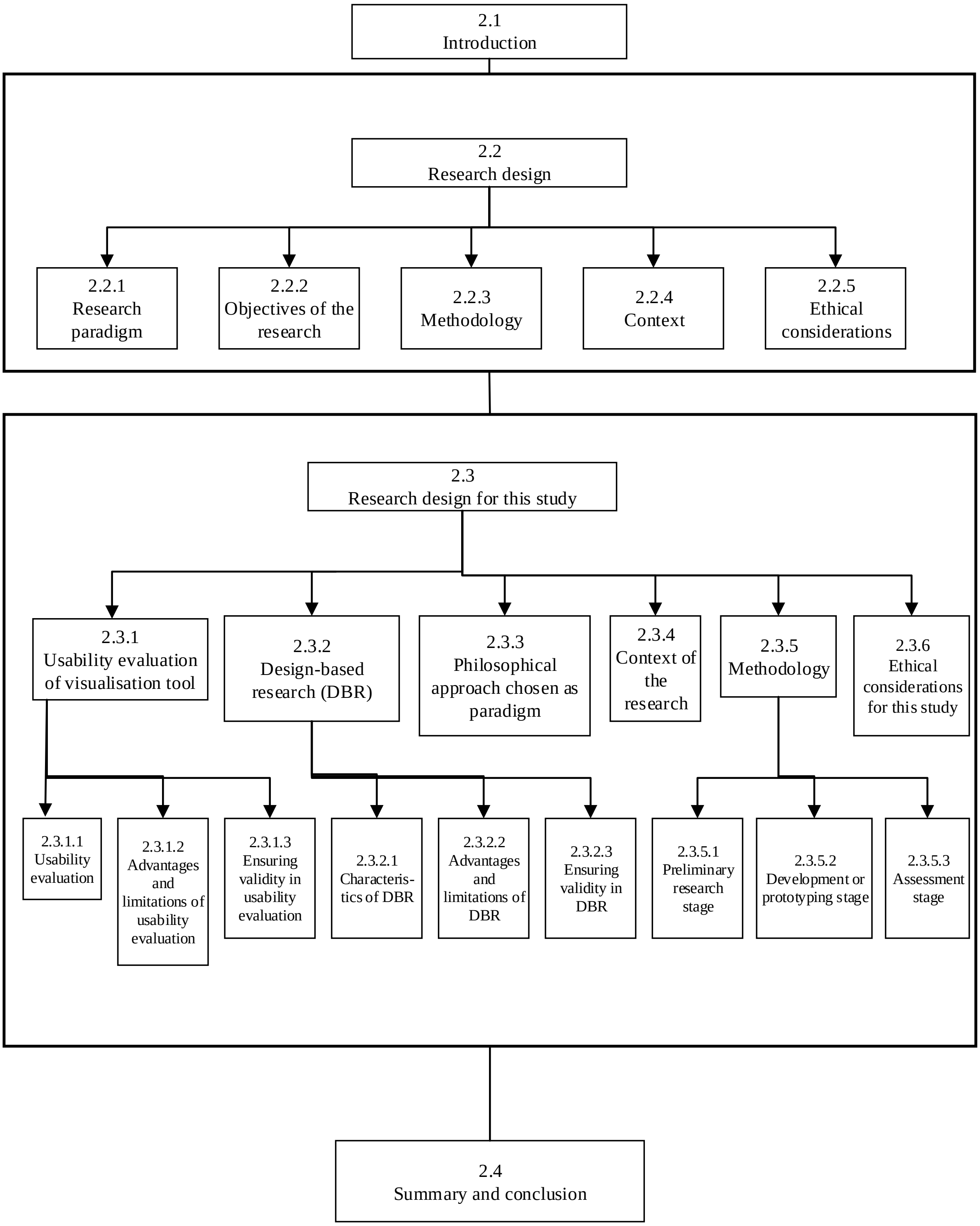
Chapter 3 details the literature review. It, therefore, provides the context and theoretical base for the research by discussing Human Computer Interaction, visualisation, knowledge visualisation principles, and technical support for KV.

Chapters 4 and 5 expatiate on the usability evaluation of knowledge visualisation tools and the evaluation of usability-based knowledge visualisation guidelines. These two chapters answer the research questions (RQ_2 and RQ_3) stated in Table 1.1, and also lay out the findings of this study, thereby answering the main research question, which as stated before, is, 'How can usability principles inform knowledge visualisation guidelines to support knowledge transfer in high-school science education?'.

Chapter 6 consists of the summary and conclusion of the dissertation. The chapter includes the practical and theoretical contribution of the research, discusses its limitations and proposes possible future research.

Finally, the referencing style used for this dissertation was that of Harvard style (University of Cape Town) and the list of appendices includes ethical clearance, informed consent forms, questionnaires, rocket launch question paper for learners, systematic literature review and publication from this research.

Map of Chapter 2 (Research design and methodology)



Chapter 2 Research design and methodology

2.1 Introduction

Researchers have argued that visualisation within the teaching and learning context, is often created by teachers, educational, learning and instructional designers with little or no input from learners (Yusoff et al., 2013; Van Biljon & Renaud, 2015a). Exploring the application of usability principles to inform KV guidelines, which can be used to support knowledge transfer, is the focus of this study and therefore, a research design and methodology which addresses these challenges is discussed in this chapter.

The previous introductory chapter (Chapter 1) provided an overview of the research, presented the rationale for the study and a brief insight into how the research questions were addressed. This chapter (Chapter 2) provides a background to the philosophical stances of the research, presents an overview of quantitative and qualitative research in computer science, and describes the research design and methodology applied to this study. A literature review, according to Onwuegbuzie and Frels (2016), can be regarded as a data collection tool. That perspective holds true for this research as the literature review, discussed in the next chapter (Chapter 3) plays an integral part in the research methodology of this study, as the data collection process is pertinent to the research methodology described in this chapter (Chapter 2).

This study was carried out in two steps: firstly, to evaluate visualisation tools and, secondly, to evaluate usability-based knowledge visualisation guidelines. Section 2.2 describes research design in general, while section 2.3 describes in detail the research design and methodological structure adopted for this study. Subsequent sub-sections describe in detail each aspect of this structure. They are outlined as follows: the methodology used for the evaluation of visualisation tool; the DBR approach used in this study; the objectives of this study; the philosophical paradigm applicable to this research; the context in which the research is orchestrated; and the ethical considerations for this study. DBR utilizes various research and data gathering methods and for this study, usability testing, questionnaires and observation were employed. Section 2.4 consist of the summary and conclusion of the chapter.

2.2 Research design

A research design can be defined as an outline of how a researcher plans to orchestrate the research (Mouton, 2011); a blueprint for the collection, measurement and analysis of facts and statistics gathered (Kothari, 2004). It provides an overall framework of the link between writing the research hypothesis and the execution of the research. Various authors from literature have provided, and are still providing, various ways by which a research design can be structured. Kothari (2004) explained that a research design must contain: (a) a clear statement of the research problem; (b) procedures and techniques to be used for gathering information; (c) the population to be studied; and (d) methods to be used in processing and analysing data. According to Durrheim (2006), a series of actions must be specified while designing a research effort to ensure that the researcher arrives at valid conclusions. These actions include identifying: (a) the philosophical paradigm (which is dependent on the nature of the research question and the researcher's beliefs and values (Oates, 2006)); (b) the aims and objectives of the research; (c) research methodology (process used to collect and analyse data); (d) the context or background in which the research took place. This research involved human participants and ethical standards were adhered to during the whole process (Oates, 2006; Cheek, 2008).

To this end, the research design steps adopted for this study were those propounded by Durrheim (2006) and the following sub-sections will elaborate on each of them in the series of actions mentioned above.

2.2.1 Research paradigm

The word paradigm originated from the Greek word *paradeigma*, meaning 'pattern'. Kuhn (1982) was the first to use the term to denote a conceptual framework shared by a community of scientists, and, by so doing, gave them a convenient model for solving problems. It can be defined as "a pattern or a model or a shared way of thinking" (Oates 2006, p.13). It is the skeleton of scientific and academic ideas, values and assumptions (Olsen, Lodwick & Dunlap, 1992).

A research paradigm has an immanent reflection of our beliefs about the world we live in or want to live in (Lather, 1986). According to Oates (2006), most research studies on Information System and Computing are based on one of three different philosophical paradigms, namely positivism, interpretivism or critical research. Although, these philosophical paradigms are most dominant in Information Systems and Software Engineering (Mora, Gelman, Steenkamp & Raisinghani, 2012), a fourth one, pragmatism, is a more adequate research paradigm for design research, according to Lee and Nickerson (2010).

The following paragraphs provide a brief overview of positivism, interpretivism, critical research and pragmatism:

- Positivism is intrinsic to the scientific method as it centres on what can be observed and measured. A positivist operates by the law of causes and effects that are identifiable if the unique approach of scientific method is applied (Krause, 2005). Positivism is often perceived as a more acceptable research paradigm because it enables the researcher to be objective and personal values and beliefs do not have an effect on the research, thus, findings are consistent, value-free and replicable (De Villiers 2012).

- The interpretivism research paradigm is based on real world phenomena, with the view that reality is subjective and differs from one individual to another (Guba & Lincoln, 1994). Unlike positivist research, interpretivism does not aim to prove or disprove a hypothesis but to show how all the factors in a particular social setting are related and interdependent (Oates, 2006). An interpretivist argues that scientists cannot but influence the phenomena they study and be influenced in turn.

- Though similar to the interpretivism research, critical researchers take cognisance of the fact that the real world is malleable due to the influence of human action. They argue that social reality and history influence people's experiences and worldviews (Ponterotto, 2005; Oates, 2006). Thus, the aim of critical researchers according to (Oates 2006, p.297) is to: "focus on the power relations, conflicts and contradictions in our modern world, and help to eliminate them as causes of alienation and domination".

- Pragmatism is a philosophy concerned with action that aligns itself with solving practical problems in the real world (Kilpinen, 2008; Feilzer, 2010). This type of research paradigm is considered appropriate for research studies whose approach does not merely observe the world but, instead, intervenes in it (Goldkuhl, 2012).

The philosophical approach used in this research is the pragmatic approach and is accounted for in detail in section 2.3.3.

2.2.2 Objectives of the research

The objectives of the research are the specific steps to be taken in order to achieve an aim (Oates, 2006). Usually a research study will have one broad aim while having several specific objectives (Thomas & Hodges, 2010). The research problem that inspired this study, together with the objectives of the study can be found in section 1.3.2. To recap, the objectives are: to identify knowledge visualisation principles applicable to teaching and learning from literature; to identify usability principles relevant to knowledge visualisation; to identify usability principles relevant for the selection of visualisation tools; and to investigate how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation in a way that the teacher can assess the quality of knowledge that has been transferred to the learner.

2.2.3 Methodology

A research methodology refers to the way, or manner, in which the researcher carries out the research (Kumar, 2019). It comprises the processes used to collect and analyse the data (Tashakkori & Teddlie, 2010).

The three research approaches that can be used are: qualitative, quantitative or mixed methods. The following paragraphs give a brief overview of each approach:

- **Qualitative research** attempts to uncover the meaning and significance of human behaviour and experience. The approach tends to develop a theory or look for a pattern of meaning on the basis of data collected. Qualitative data collected are usually done in a natural setting via for example: observations, interviews, memos, minutes of meetings, documentary films, literary texts, memos and recollections (Walliman, 2011).
- **Quantitative research** involves collecting and converting data into numerical forms so that it can be analysed using mathematically based methods (mostly statistical calculations) and conclusions drawn (Oates, 2006; Yilmaz, 2013). A quantitative research approach is generally associated with the positivist or post-positivist paradigm.
- **Mixed methods research** (also called pragmatic approach) involves both the quantitative and qualitative approaches. It takes into consideration the limitations of both research approaches and recognises that they can complement one another. According to Wang and Hannafin (2011), it is a research method that can be used to maximize the credibility of a research study.

The methodology used in this research is described in section 2.3.5.

2.2.4 Context

The context refers to the environment and conditions in which the research is carried out (Oates, 2006); it provides an insight into the background from which the research problem unfolds, and is then refined into research questions and objectives (Oates, 2006; Walliman, 2011; Creswell, 2014). The context is important, as it allows for meaningful understanding of the findings of the research (Schoeman, 2015). According to Durrheim (2006), the collection of data should be in the natural context in which it transpires.

The context in which this research was done is addressed in section 2.3.4.

2.2.5 Ethical considerations

The birth of modern research ethics began with a desire to protect human subjects involved in research projects (Fakruddin, Mannan, Chowdhury, Mazumdar, Hossain & Afroz, 2013). According to Marczyk, DeMatteo and Festinger (2017), ethical research is guided by philosophical and administrative principles which may differ slightly across jurisdictions and disciplines. These principles are:

- *Autonomy and respect for person* refers to the ability of a person to make his or her own decisions about the kind of research they want to be involved in, as well as requirement for voluntary participation.
- Consent from participants.
- *Beneficence* requires that the benefit of the research to the participants be maximised, while minimizing potential harms and discomforts. In summary, it entails having the interest of research participants in mind.
- *Justice* in research requires that the selection of research participants must follow a fair procedure and that appropriate participants are selected.

As stated in section 2.2, this research involved human participants and the ethical considerations applied in this study are discussed in section 2.3.6.

2.3 Research design for this study

This study was carried out in two steps; firstly, to evaluate visualisation tools and, secondly, to evaluate usability-based knowledge visualisation guidelines (Section 1.3.2).

Figure 2.1 below is a diagrammatic representation of the research process flowchart for this study. HCI usability principles and usability-based knowledge visualisation guidelines were extracted from literature and used for the selection of the KV tool and the prioritisation of KV guidelines respectively. In Step 1, usability evaluation of the KV tools was carried out using HCI usability principles. Detailed steps carried out during the evaluation are discussed in Chapter 4. In Step 2, the effect of usability-based knowledge visualisation guidelines during knowledge transfer in high-school science education was evaluated and this resulted in the prioritisation of KV guidelines. Details of this evaluation and the results are discussed in Chapter 5. Qualitative and quantitative data analysis of the results was carried out.

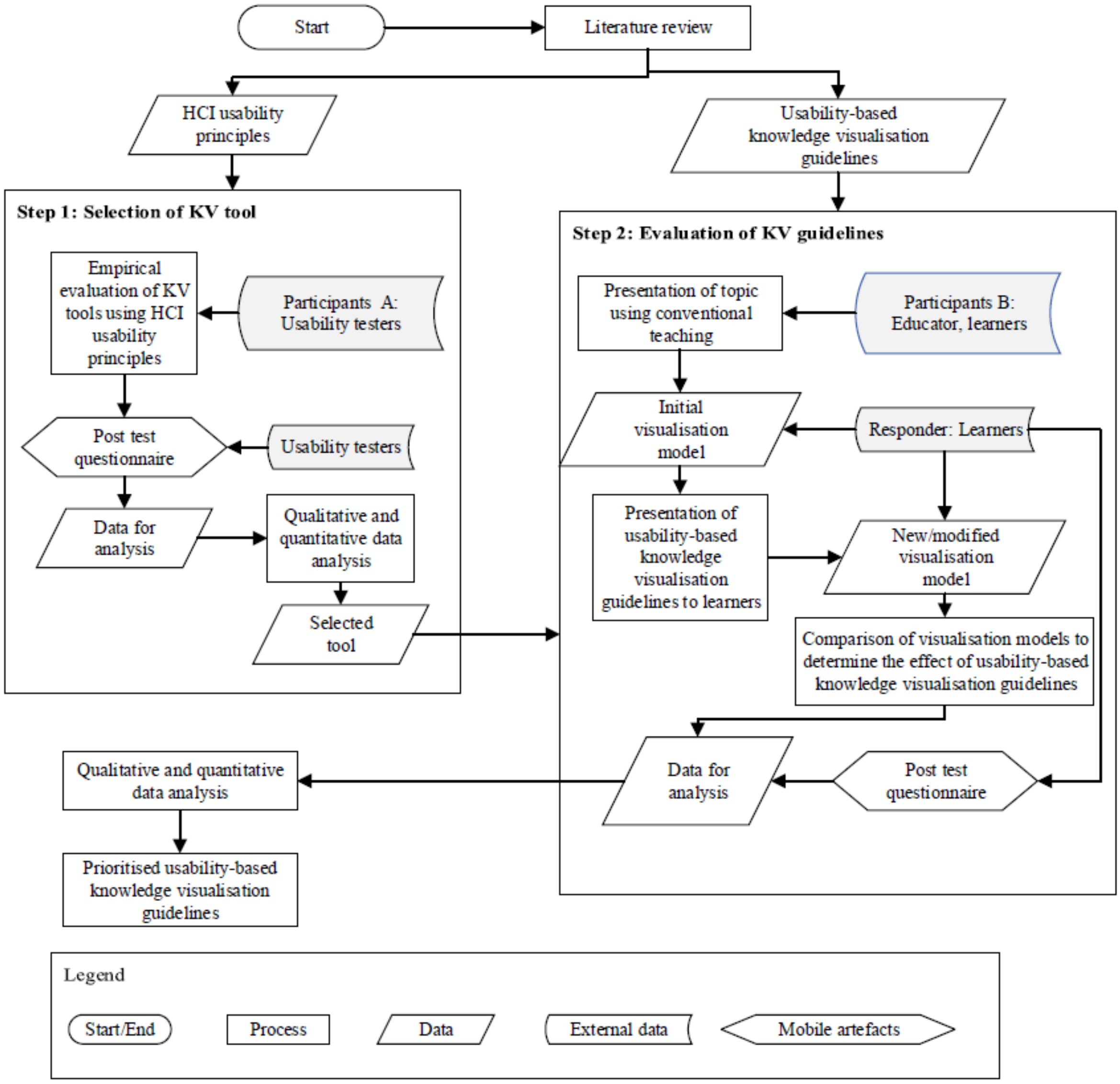


Figure 2.1: Research process flowchart

The previous section provided an overview of what constitutes a research design. Each of these parts are discussed in detail in relation to this study. In the next section, section 2.3.1, the usability evaluation for the visualisation tool is discussed while section 2.3.2 expatiates on the DBR design used for this study.

2.3.1 Usability evaluation of visualisation tool

The evaluation of user experience and its relationship to usability is an important aspect of HCI related research (Arhippainen & Tähti, 2003). Usability evaluation according to Bastien (2010), is an essential step in user-centered design processes which serve as a way of ensuring that interactive systems are attuned to the users and their projects, with little or no negative outcomes during usage.

For this study, the user-based evaluation was adopted.

2.3.1.1 Usability evaluation

Usability evaluation is an evaluation method for testing interactive systems that focuses on how users can learn and use a product to perform a specific task under specified conditions (Liu, 2008; Preece, Rogers & Sharp, 2015). Freiberg and Baumeister (2008) proposed three main categories of usability evaluation techniques namely expert evaluation (inspection based), user-based evaluation, and hybrid approaches. Bastien (2010) also mentions inspection-based and user-based but adds model-based evaluation. As stated in the previous section, the user-based evaluation (usability testing) was adopted for this study. Participants of this evaluation method are usually observed in a controlled environment while data is collected using a combination of methods e.g. questionnaire, researcher taking notes, interview etc. (Albert & Tullis, 2013). As stated in section 2.1, this study employed usability testing, questionnaires, and observation for its usability evaluation. A user-based usability evaluation was carried out for the selection of the appropriate visualisation tool to be used for the implementation of KV by learners.

The table below shows the basic steps necessary during the implementation of a usability test as stated by Bastien (2010), and how each step was implemented in this study is explained in the table:

Table 2.1 Steps taken during usability evaluation (Bastien, 2010)

Steps in usability test	Relation to this study
1. Definition of the test objectives	To select the most appropriate KV tool subject to HCI usability principles identified in section 3.7.3 and Table 3.9.
2. Qualification and recruitment of tests participants	Five usability testers (3 males) were selected, with over 5-years of user-experience in Information Technology devices, to ensure a cross-section of participants were selected (Krueger & Casey, 2009; The City University of New York, 2012)
3. Selection of tasks participants will have to realize 4. The creation and description of the task scenarios	The interaction consisted of the task to create KV images using the two mobile application platforms. The images were a representation of how rockets are launched, a model which can be applied in STEM education
5. The choice of the measures that will be taken as well as how data will be recorded	To gather statistical data for the test, questionnaires were used which, according to Moczarny (2011), included: - User-profile demographic details i.e. age, gender, level of education, employment status. - Scalar questions: Users are asked to judge specific usability principles based on a numeric scale known as Likert scaling, for example, users were asked to rate the flexibility of the tool based on 'ease of use' etc. - Open-ended questions: Users were asked, for example, to list additional usability functionality that should be present in the tool that was not mentioned in the questionnaire. The questionnaires were administered to testers after they had interacted with the two KV tools. Once the task was finished, they filled in the questionnaire to capture their usability perception regarding each principle stated in section 3.7.3.
6. Preparation of the test materials and of the test environment (the usability laboratory)	A controlled environment was used to increase the attention span of testers, thus providing considerable information (Carpendale, 2008). Digital devices (i.e. laptops and tablets) were provided with pre-installed versions of the visualisation tools, together with internet access.

7. Choice of the tester, and the design of the test protocol (i.e. instructions, design protocol, etc.)	Subject of section 4.2.
8. The data analysis procedures 9. The presentation and communication of the test results	In addition to the questionnaire administered after the test, the researcher was able to observe the interaction of each tester with each tool during the test. The outcome of the surveys was evaluated using statistical analysis and the outcome of the result is stated in section 4.2.6.

2.3.1.2 Advantages and limitations of usability evaluation

The following are some of the advantages of usability evaluation as discussed in literature:

- To encourage a widespread adoption of KV tools, it is important to subject them to a variety of evaluation methods (Carpendale, 2008), a characteristic of usability evaluation.
- The use of KV tools is user-centred and usability evaluation is an evaluation method that draws conclusions based on user experience as opposed to theoretical proofs (Carver, Syriani & Gray, 2011; Whiteson & Littman, 2011; Toribio-guzmán et al., 2017).
- A user-based evaluation has the advantage of directly exploring the user's interaction with the mobile application interface, and to collect information about potential usability problems and user preferences at first hand (Freiberg & Baumeister, 2008; Toribio-guzmán et al., 2017).

The following are some of the limitations of usability evaluation as discussed in literature:

- There is a possibility that the participants may be more familiar with one KV tool than the other, and this may skew the results (Carpendale, 2008).
- It is almost impossible to have an ideal environment while performing a usability test (Chin, 2001).
- A usability evaluation can be considered expensive in relation to the time and human resources needed (Wilson, 2008; Bastien, 2010; Nayebi, Desharnais & Abran, 2012).
- User experience can be affected by isolating participants from environmental factors, that is, by using a controlled environment (Nayebi, Desharnais & Abran, 2012).
- There is a lack of tool support for automatic usability evaluation (Wilson, 2008; Lettner & Holzmann, 2012).

2.3.1.3 Ensuring validity in usability evaluation

To make certain that experimental results are valid for the target population, Panach, Condori-Fernandez, Vos, Aquino and Valverde (2011) and (Remy et al., 2018) explain that it is essential to consider a validity evaluation. A claim of validity can be strengthened by using verbatim quotations, triangulation of data and reflexivity (Easterbrook, Singer, Storey & Damian, 2008). The validity of this report is reinforced by triangulation of data, that is, a common data set acquired through the use of questionnaires, interviews and observations. In addition, the items selected for the construct of the questionnaire were mainly adapted from literature and this helps to ensure content validity (Wang & Liao, 2006).

2.3.2 Design-based research (DBR)

The research design employed by this study, DBR, is the educational variation of design research, used in educational technology and e-learning (De Villiers & Harpur, 2013; Wang et al., 2014). DBR can be defined as “a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories” (Wang & Hannafin, 2005:6).

Design science is a science that relates to man-made phenomena whose characteristic features are problem-solving, innovation, building and evaluation of reliable artefacts and interventions (De Villiers, 2012; Kuechler & Vaishnavi, 2012; De Villiers & Harpur, 2013). Design research (DR) emanated from design science, and its origin can be credited to Nobel laureate Herbert Alexander Simon (Simon, 1981), who discerned between natural sciences (study of natural phenomenon) and design sciences (study of man-made objects and artificial phenomenon). De Villiers (2012) further explains that design research is called *design science research* in Information Systems (IS) and Information Technology (IT) while in educational technology and e-learning, it is referred to as *design-based research*. The use of DBR for this study is based on the potential of DBR to impact teaching and learning in naturalistic settings (Barab & Squire, 2004).

This study aimed to investigate how learners can use KV to internalise knowledge while simultaneously focusing on the evaluation of usability-based knowledge visualisation guidelines. This process was implemented using digital technology. According to De Villiers and Harpur (2013), DBR has the capability to advance and evaluate the use of digital technology in teaching and learning, thus making it the research design of choice for this study.

Table 2.2 is an adaptation from De Villiers (2012), showing the similarities and differences between design-science and DBR, while also indicating the relevance to this study.

Table 2.2 Similarities and differences between design-science and design-based research (adapted from De Villiers, 2012)

Properties	Design research		Relevance to this study
	Design-science research	**Design-based research**	
Goals	1) Introduction of novel artefacts to enhance performance. Problem-solving via invention, evaluation, measurement, and impact studies. 2) Theories emerge; existing theories are elaborated.	1) Implementation of novel educational technology solutions in complex situations. New products and practices in real-world settings. 2) Development/extension of models and contextual design theories shared with practitioners and designers.	This research identifies with the real world situation by utilising KV in teaching and learning (Chapter 1).
	They both have a dual focus: developing products and contributing to the body of knowledge.		
Distinct features	Rooted in engineering. Use of novel artefacts to change real- world states. Solutions generated by human cognition, creativity and teamwork in ill- defined, complex areas. ‘Satisficing’ findings, obtaining satisfactory solutions but sacrificing exhaustive search.	Rigorous and reflective inquiry into real problems in education or training Contextually-sensitive. Design experiments to find both practical outputs (innovative designs and prototypes) and theoretical outputs (contextualized theories).	The need to investigate the utilization of KV by learners (Chapter 1)
Processes	‘Design’ relating to both products and processes. Products: complete systems and building blocks, i.e. constructs, models, methods and instantiations. Processes: complementary activities of construction-in-context and cyclic evaluation studies, involving mathematical modelling and empirical studies.	Convergence of research, design and feedback. Continuous cycles of analysis, design, development, enactment, evaluation and redesign. Pragmatic inquiry, evidence-based claims, validation by use. Multi-disciplinary expertise. Interpretive paradigm, qualitative studies and mixed methods.	This study adopted the pragmatic philosophical approach (section 2.3.3). Two iterative cycles of analysis were undertaken to evaluate the application of KV guidelines (Chapter 5). Data collection was via mixed methods (sections 2.3.1.1 and 2.3.1.3).
	They both have iterative/cyclic design processes		
Application	Information Systems Educational	Educational Technology / e-Learning	This study is based on the implementation of KV using digital technology in the context of teaching and learning (sections 2.3.4 and 3.7).

2.3.2.1 Characteristics of design-based research

The following characteristics of DBR have been extracted and synthesised from books and papers by Anderson and Shattuk (2016), Dawson and Dewitt (2013), Bakker and Eerde (2015), Easterday, Rees Lewis and Gerber (2014), Stemberger and Cenci (2014), Kennedy-Clark (2013), De Villiers and Harpur (2013), De Villiers (2012), Schoeman (2015) and Markauskaite, Freebody and Irwin (2011) as shown in Table 2.3 below:

Table 2.3: Characteristics of design-based research from literature

Characteristics	**Reference**
It can be applied to a real-life educational setting	(Markauskaite, Freebody & Irwin, 2011; De Villiers, 2012; Dawson & Dewitt, 2013; Stemberger & Cenci, 2014; Bakker & Eerde, 2015; Anderson & Shattuck, 2016)
It refines both theory and practice	(Markauskaite, Freebody & Irwin, 2011; Bakker & Eerde, 2015; Schoeman, 2015; Anderson & Shattuck, 2016)
It incorporates pragmatic goals	(Markauskaite, Freebody & Irwin, 2011; De Villiers, 2012; Stemberger & Cenci, 2014; Anderson & Shattuck, 2016)
Iterative cycles of analysis, design, prototypes, development, enactment, evaluation, analysis, redesign	(Markauskaite, Freebody & Irwin, 2011; De Villiers, 2012; Dawson & Dewitt, 2013; De Villiers & Harpur, 2013; Kennedy-Clark, 2013; Easterday, Rees Lewis & Gerber, 2014; Bakker & Eerde, 2015)
It is grounded in strong theoretical framework	(Dawson & Dewitt, 2013; Anderson & Shattuck, 2016)
Collaboration between researchers, designers, practitioners and participants	(Markauskaite, Freebody & Irwin, 2011; Dawson & Dewitt, 2013; Anderson & Shattuck, 2016)
Mixed method of data collection	(Markauskaite, Freebody & Irwin, 2011; De Villiers, 2012; Kennedy-Clark, 2013; Stemberger & Cenci, 2014)

Table 2.4 below is an extract from Wang and Hannafin (2005), stating how the characteristics of a DBR are related to this study:

Table 2.4: Characteristics of design-based research and corresponding position in the dissertation (adapted from Wang & Hannafin, 2005)

Characteristics	Explanations	Position
Pragmatic	• DBR refines both theory and practice. • The value of theory is appraised by the extent to which principles inform and improve practice.	In reference to the main research question (section 1.3.2), this study adopted the pragmatic philosophical paradigm (section 2.3.3).
Grounded	• Design is theory-driven and grounded in relevant research, theory and practice. • Design is conducted in real-world settings and the design process is embedded in, and studied through, DBR.	Theoretical contribution: Combining HCI usability principles and KV guidelines to create usability-based knowledge visualisation guidelines (Table 3.6) This research involves human participants in the context of teaching and learning (Sections 1.5, 2.2 and 2.3.4)
Interactive, iterative, and flexible	• Designers are involved in the design processes and work together with participants. • Processes are iterative cycle of analysis, design, implementation, and redesign. • Initial plan is usually insufficiently detailed so that designers can make deliberate changes when necessary.	Chapters 4 and 5
Integrative	• Mixed research methods are used to maximize the credibility of ongoing research. • Methods vary during different phases as new needs and issues emerge and the focus of the research evolves. • Rigor is purposefully maintained, and discipline applied appropriate to the development phase.	To ensure validity, a mixed research method comprising questionnaires, interviews and observations was used for the usability evaluation of the visualisation tools and the evaluation of KV guidelines (Table 2.1, Section 2.3, Chapters 4 and 5)
Contextual	• The research process, research findings, and changes from the initial plan are documented. • Research results are connected with the design process and the setting. • The content and depth of generated design principles varies. • Guidance for applying generated principles is needed.	Chapters 4 and 5

2.3.2.2 Advantages and limitations of design-based research

A notable characteristic of a DBR is the collaboration between researchers, designers, practitioners and participants (Markauskaite, Freebody & Irwin, 2011; Dawson & Dewitt, 2013; Anderson & Shattuck, 2016). However, Barab and Squaire (2004, p. 10) argue that "if a researcher is intimately involved in the conceptualisation, design, development, implementation, and researching of a pedagogical approach, then ensuring that researchers can make credible and trustworthy assertions is a challenge." In addition, Mingfong, San and Ming (2010) point out that there are theoretical and practical challenges that hinder the design process of a DBR.

2.3.2.3 Ensuring validity in design-based research

A DBR study uses a mixed research methodology for its processes (De Villiers, 2012) which also incorporates the application of data triangulation (Stemberger & Cenci, 2014). The use of multiple sources of data (triangulation) enhances the reliability and internal validity of findings (Stavros & Westberg, 2009; Kennedy-Clark, 2013; Plomp, 2013; Bakker & Eerde, 2015; Denzin, 2017). The validity of a process may also be bolstered by combining different data sources, type and analysis (Holloway, Brown & Shipway, 2010; Fusch, 2013). According to Plomp (2013), the weakness in one form of data collection will be counterbalanced by the strength of another.

The iterative characteristics of DBR also enhance the validity of the research by affirming findings and aligning theory, design and practice (De Villiers & Harpur, 2013; Easterday, Rees Lewis & Gerber, 2014).

In addition, DBR aims to design a high-quality solution for a problem in a naturalistic setting (Plomp, 2013) and this can provide a sense of validity to the research in the educational context (Anderson & Shattuck, 2016).

2.3.3 Philosophical approach chosen as paradigm

A DBR is managed in a real world situation and, based on this, it has the potential to impact teaching and learning in naturalistic settings (Barab & Squire, 2004; Markauskaite, Freebody & Irwin, 2011; Dawson & Dewitt, 2013; Stemberger & Cenci, 2014; Anderson & Shattuck, 2016). The pragmatic research paradigm aligns itself with solving practical problems in the real world (Kilpinen, 2008; Feilzer, 2010) and therefore supports design research (De Villiers, 2005; Hevner & Chatterjee, 2010). As noted in section 2.3.2, design research is called DBR in educational technology and e-learning. Barab and Squire (2004) and Wang and Hannafin (2005) also noted that DBR has a pragmatic philosophical footing and, therefore, this research study adopted it. The next section explains the contexts relevant to this study.

2.3.4 Context of the research

The background of the participants and the environment and conditions in which this study took place had an influence on the overall outcome of the research. The context of this study is the application of KV in teaching and learning. According to Gabriella, Marco and Alessio (2017), a context is either local or global, depending on the scope. The background of the learners provides an insight into the context from which the research problem emanated (Walliman, 2011; Creswell, 2014) and this is explained in the section below.

Local context

This research was conducted with the involvement of South African high school learners in the field of science. The learners were selected from various schools in Gauteng (private and public), with little or no consideration of their academic performances. This was to enable the researcher to have a fair sample of participants. The topic used for this study was 'How rockets are launched,' a model which can be applied in STEM (*acronym for Science, Technology, Education and Mathematics*) education.

Also, the implementation of the research test (Appendix E) by the learners, i.e. producing a diagrammatic representation of how rockets are launched, was carried out both on paper and with the use of a digital device (laptop). The efficiency of the learners in the use of digital technology may have been influenced by their personal background and/or the availability of ICT (information and communications technology) in their schools. The test environment used for this study was similar to a formal learning setting, with the provision of digital devices for each learner. The background information of each participant was captured in the survey carried out by the researcher. This can be found in section 5.2.1.

Global context

The global context for this study relates to the application of KV in e-learning, and how the application of the contribution of this study can be extended to all high school science learners within South Africa and beyond. It is, however, worth noting that broader contextual considerations such as language barriers, culture, beliefs, ideology (Gabriella, Marco &

Alessio, 2017) might have impacted on the outcome of the research. Additionally, learners from schools with limited infrastructures and minimal availability of modern technology may be at a disadvantage when compared with learners from first world countries. For example, one of the learners noted that Padlet had been used in his school in the past and, thus he had some experience of the visualisation tool.

2.3.5 Methodology

The methodology followed in this study is based on Plomp's (2013) three distinct stages of DBR which are: preliminary research, a prototyping phase and an assessment phase. The following sub-sections address each of these stages and also show both where in this dissertation each of the components mentioned is implemented and the methods used to do so.

2.3.5.1 Preliminary research stage

In the preliminary research stage, a review of past and present literature is conducted on research studies that address similar research questions to this study. The outcome of this is a conceptual or theoretical framework for the study (Kennedy-Clark, 2013). To achieve this, a systematic literature review (SLR) was conducted, and the summary table can be found in Chapter 3 and Appendix F.

2.3.5.2 Development or prototyping stage

The development or prototyping phase can also be referred to as the iterative design phase. For this study, two cycles of iteration of the approach were undertaken in which learners were required to produce two diagrammatic representations of a rocket launch and were subjected to usability-based knowledge visualisation guidelines. The process leading to both cycles is described in Chapter 2, 4 and 5, together with the outcome of the result. Both quantitative and qualitative data were captured and analysed accordingly. The validity of the results was verified by triangulation of data as explained in sections 2.3.1.3 and 2.3.2.3. The artefact developed is the usability-based knowledge visualisation guidelines.

In Figure 2.2 below, the flowchart for the two cycles of iteration is presented. In the first iteration, learners were instructed on ‘How rockets are launched’ using the conventional way of teaching. After the lecture, learners were asked to complete a test paper which required them to give a diagrammatic representation of how rockets are launched. The initial visualisation model produced by the learners was evaluated by the researcher to check the level of conformity to usability-based knowledge visualisation guidelines. For the second iteration, usability-based knowledge visualisation guidelines were presented to the learners who were then asked to modify or recreate the initial visualisation model. The new image produced by the learners was evaluated by the researcher to check the level of conformity to usability-based knowledge visualisation guidelines. The outcome of the evaluation is discussed extensively in Chapter 5, showing the degree of conformity of the learners before and after the brief to apply usability-based knowledge visualisation guidelines and with the product being the prioritisation of KV guidelines.

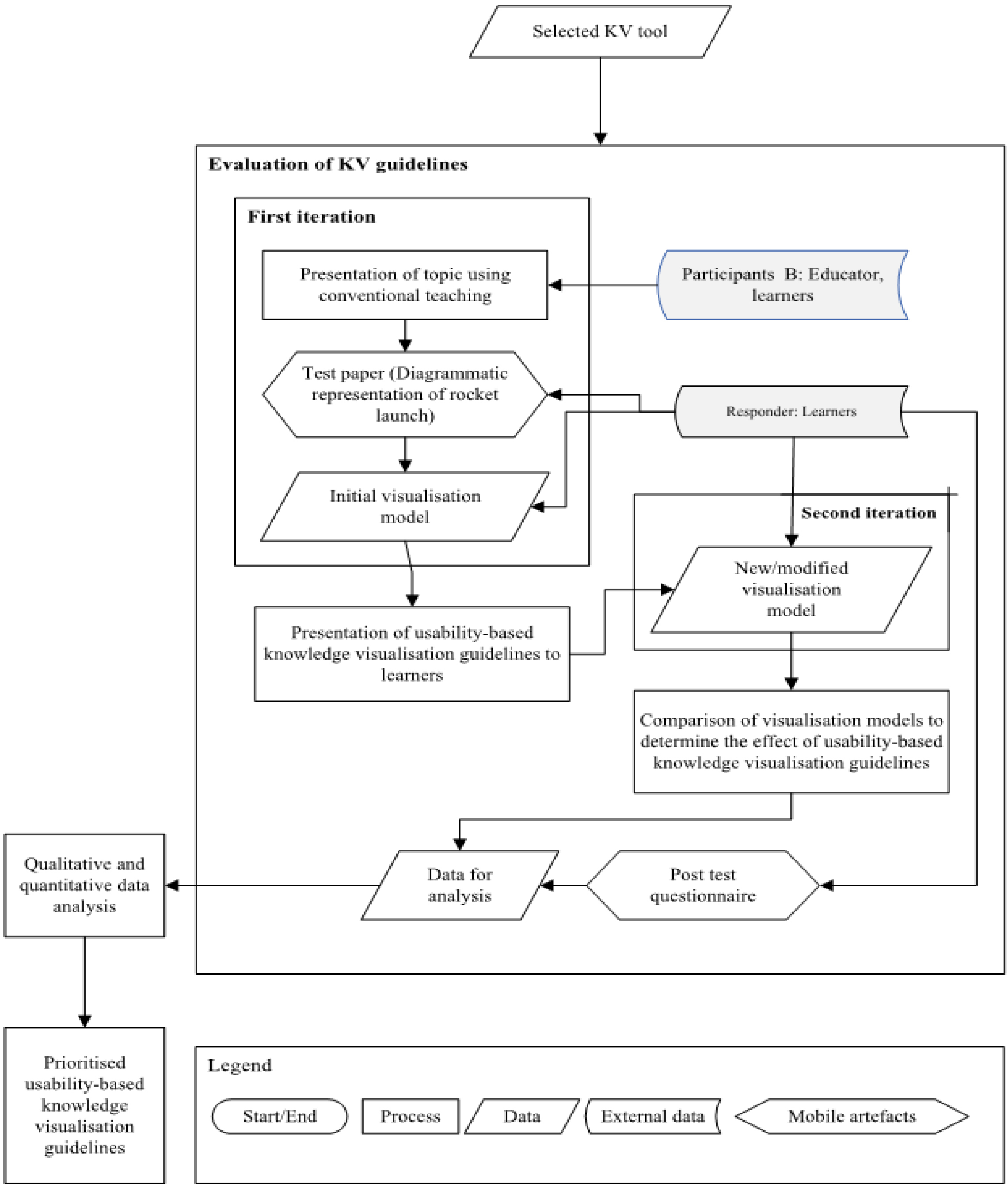


Figure 2.2: Iteration steps for the evaluation of usability-based knowledge visualisation guidelines

2.3.5.3 Assessment stage

The assessment stage is the final phase of the DBR and it includes the practical, theoretical and societal contribution. This phase shows how the outcome of the investigation meets the research problems and objectives stated in Table 1.1. This can be found in Chapter 6, where the conclusions of the findings of the study are discussed. In addition, recommendations for future research are outlined.

Table 2.5: Phases of a design-based research with corresponding positions in this study (adapted from Plomp, 2006, p. 30**)**

Stage	Short description of activities	Position
Preliminary research	Review of the literature and of (past and/or present) projects addressing questions similar to the ones in this study. This results in a framework (guidelines) and first blueprint for the intervention.	Chapter 3
Development or Prototyping phase	Development of a sequence of prototypes that will be tried out and revised on the basis of formative evaluations. Early prototypes can be just paper-based for which the formative evaluation takes place via expert judgments resulting in expected practicality	Chapter 4 and 5
Assessment phase	Evaluate whether target users can work with intervention (actual practicality) and are willing to apply it in their teaching (relevance & sustainability). Also whether the intervention is effective.	Chapter 5 and 6

2.3.6 Ethical considerations for this study

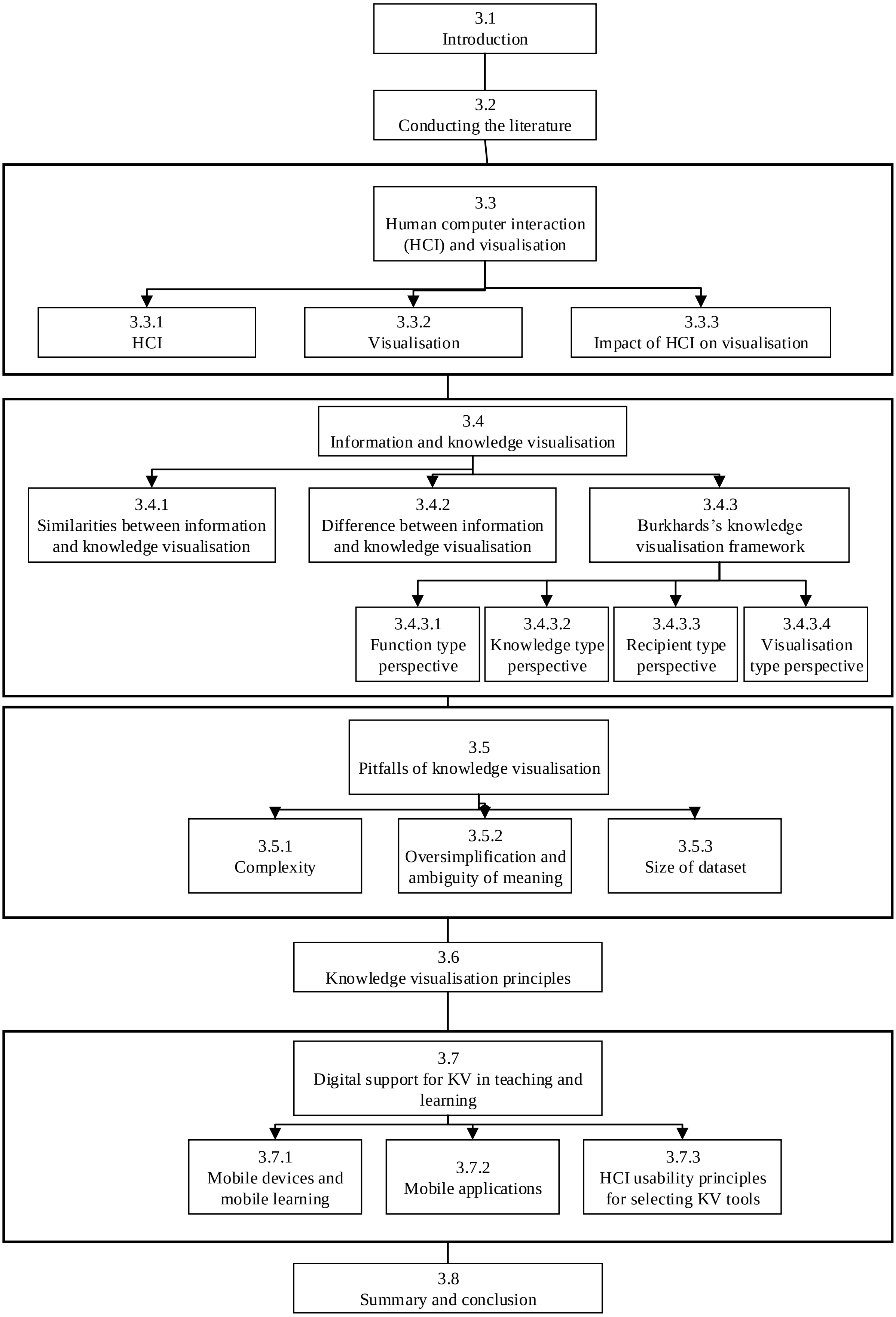
The ethical clearance for this Masters' study was obtained from the School of Computing Ethics Sub-Committee in the College of Science, Engineering and Technology at UNISA. Included in the application for ethical clearance were the following: the research proposal; informed consent forms for usability testers; informed consent forms for parents of learners; participant information sheet; questionnaire for effect of KV guidelines; questionnaire for KV tool evaluation process; and questionnaire for KV evaluation process. The letter confirming that ethical clearance was approved is included in Appendix A.

2.4 Summary and conclusion

This chapter presented the research design and methodology used in this study. This research identifies with real world situations and thus, makes DBR the research design of choice for this study as explained in section 2.3.2. Some of the distinct features of a DBR are the ability to detect practical and theoretical outputs which were achieved by investigating the utilization of KV by learners. The pragmatic philosophical approach adopted ensured evidence-based claims and validation by its use. The methodology used, based on the three distinct stages of a DBR, were: preliminary research stage; development or prototyping stage; and assessment stage. The use of humans for this study necessitated ethical clearance as discussed in section 2.3.6.

The next chapter is the literature review chapter (Chapter 3) which, as stated in section 2.1. is integral to the research methodology.

Map of Chapter 3 (Literature review)



Chapter 3 Literature review

3.1 Introduction

This chapter provides the literature context and theoretical background for the research. This is a study that involves, an area that intersects with information visualisation and knowledge management (Bertschi, Bresciani, Crawford, Goebel, Kienreich, Lindner, Sabol & Moere 2011). Wang and Jacobson (2011) argue that technology has been proven to enable and promote visualisation in various ways. To this end, the topics that will be addressed in this literature review chapter are: Human computer interaction (HCI), visualisation, information and KV; Burkhard's knowledge visualisation framework (Burkhard, 2005a); and knowledge visualisation principles. Figure 3.1 shows the relationship among these topics and their contribution to the background for this research.

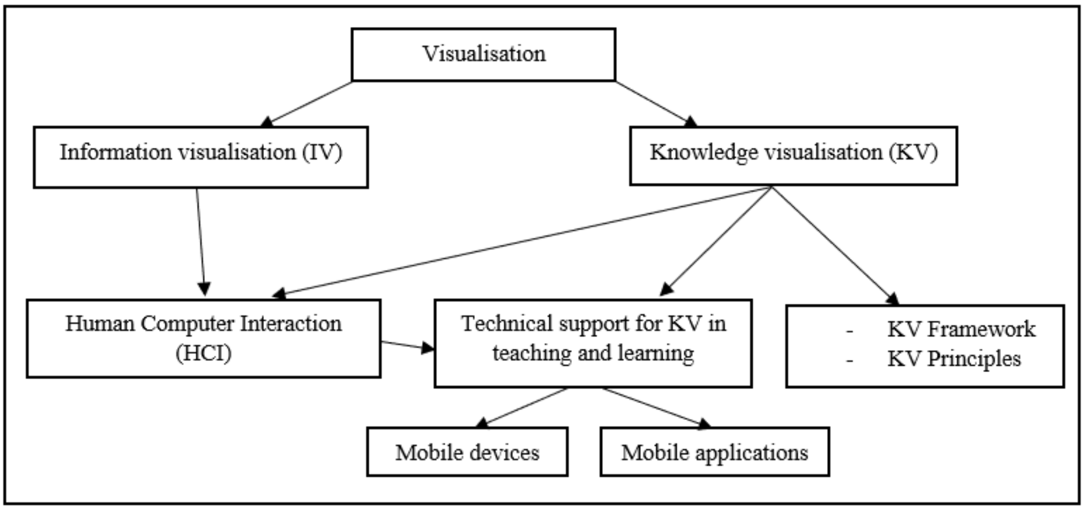


Figure 3.1 Relationship between literature review topics

In section 3.2, a detailed description of how the literature review was conducted is discussed while Section 3.3 and its sub-sections discuss human computer interaction and its impact on visualisation. In section 3.4, information and knowledge visualisation are explained, and in the following sub-sections the similarities and differences between the two concepts are outlined. In section 3.5, the drawbacks of KV are discussed, while in section 3.6, the answer to RQ_1, that is: *What are the existing knowledge visualisation principles for teaching and learning*? is derived from the explanation of KV principles. Digital support for KV in teaching and learning is discussed in section 3.7 and its sub-sections, which answer $RQ_{2,}$ that is: *Which usability principles are relevant to knowledge visualisation?* The summary and conclusion of the chapter is presented in section 3.8.

3.2 Conducting the literature review

This research aims to facilitate KV as a communication and knowledge transfer mechanism in South African schools. To conduct the literature review, the search strings used are those that returned results containing at least one of the terms visualisation, visualization (for papers published in American English), knowledge/information visualisation, knowledge/information visualisation principles, concept maps, and usability principles as shown in Table 3.1 and Table 3.2. Data visualisation, that is, the visual representation of quantitative data in a systematic configuration (Lengler & Eppler, 2007; Khan & Khan, 2011), was excluded in this study. Although data, information and knowledge in visualisation are terms used interchangeably, given the interrelated context in which they are portrayed in literature, what they represent is not consistent and often conflicting (Chen, Ebert, Hagen, Laramee, van Liere, Ma, Ribarsky, Scheuermann & Silver, 2009; Masud, Valsecchi, Ciuccarelli, Ricci & Caviglia, 2010).

Table 3.1 contains the inclusion and exclusion criteria for the search, while Table 3.2 shows the number of relevant publications on KV in teaching and learning applicable to this study. For Table 3.2, the search was specifically in the field of computer science, and it is worth mentioning that relevant publications from the Google Scholar database were omitted. This is due to the difficulty in streamlining the search to a specific field while using the advanced search engine option. It was also observed that there were more results for the search string 'knowledge visualisation and learning' compared to the string 'knowledge visualisation and teaching'. Furthermore, there is less vetting and quality assurance on the literature included in Google Scholar.

Table 3.1: Inclusion and exclusion criteria

Inclusion	Exclusion
a. Involves knowledge/information visualisation as a primary condition. b. Includes an identifiable learner level. All learner levels are admissible. c. Includes knowledge/information visualisation in the context of teaching and learning in the field of educational and computer science. d. Published between January 2010 and December 2017.	a. Working papers, television broadcast, abstracts or hearings are excluded b. Google scholar database

Table 3.2: Relevant publications on knowledge visualisation in teaching and learning[1]

Database	Link	Knowledge visualisation AND learning	Knowledge visualisation AND teaching	Relevant publications on Knowledge visualisation in teaching and learning	
				Number	**Reference**
Google Scholar	https://scholar.google.co.za	126,000	30,800	-	-
IEEE Explore	http://0-eeexplore.ieee.org.	136	46	8	(Mengis & Eppler, 2012), (Gu, Ahmad & Sumner, 2010), (Cantal & Pena, 2015), (Zhang, Zhong & Zhang, 2010), (Bertschi et al., 2011), (Yusrizal et al., 2011), (Yusoff et al., 2013), (Li & Ning, 2011)
ACM	http://dl.acm.org/	18	18	2	(Yusoff et al., 2013), (García-sánchez & Sánchez, 2014)
Scopus	https://www.elsevier.com/solutions/scopus	21	11	7	(Cantal & Pena, 2015), (Yusoff & Dahlan, 2013), (Van Biljon & Renaud, 2015b), (Yusoff et al., 2013), (Gu, Ahmad & Sumner, 2010), (Zhang, Zhong & Zhang, 2010), (Azzouza, Azouaou & Ghomari, 2010)
Springer	www.springer.com	132	67	4	(Sun, Li & Zhu, 2016), (Wan Mohd, Embong & Zain, 2010), (Lee, Kim & Lee, 2010), (Van Biljon & Renaud, 2015b)
ISI (Web of Science)	http://login.webofknowledge.com	36	36	4	(Nahavandi, Jia & Bhatti, 2010), (Hall & Virrantaus, 2016), (Wang & Ma, 2014), (Strakhovich, 2014)

Based on the methodology used, limitations, findings and the future research suggested, the papers in Table 3.3 were selected from the systematic literature review (SLR) table located in Appendix F. As noted by Boell and Cecez-Kecmanovic (2015) and Jalali and Wohlin (2012), a SLR table can be used in collecting identifiable evidence from earlier research and help achieve a high inter-researcher reliability. For this study, the SLR was used in identifying: the foremost design methodology in KV; advantages and limitations of KV in teaching and learning; and areas of further study of KV in teaching and learning.

[1] This SLR search was carried out in January 2018

Table 3.3 Findings from literature on knowledge visualisation (KV)

Reference	Methodology	Limitations	Findings	Future research for each paper assessed
(Sun, Li & Zhu, 2016)	Action research	Domain specific	Learning abilities can be improved via the use of visualisation	Comprehensive application of visualisation methods in learning
(Ahmad, Ahmad & Rejab, 2011)	DBR	The use of conventional teaching materials (e.g. lecture notes, slide presentations etc.) is not sufficient enough to increase a learner's understanding	KV can be used to convert lecturer tacit knowledge to student explicit knowledge in teaching and learning process	The conceptual framework proposed is tested by using Structural Equation Modeling (SEM). The result will be used to revise the conceptual model
(Bertschi et al., 2011)	Case study	-	Visualization improves communication and interaction around cognitive processes	The field of KV could benefit from: - studying and measuring its impact on collaborative interactions, groupware accessibility, and social media - understanding the implications on input devices (e.g. multi-touch screens) as a form of interaction - testing on new domains such as intercultural communication - integration with Visual Analytics to build a simple and accessible means for analysing, evaluating and utilising knowledge
(Gu, Ahmad & Sumner, 2010)	DBR	The research gave a suggested learning path for learners to use as against giving room for diversity i.e. the variability of learner's literacy skills and learning styles	Learners find it difficult to effectively locate and use resources to fulfil their learning needs. The availability of this new and relevant information often leads to confusion as it does not correspond with their prior knowledge. Also, information from various sources are	Because of the diversity in learner's literacy skills and learning styles, a study could be done on how to customize/modify learning paths and note the effects of such customization on the model proposed

			sometimes inconsistent and incompatible	
Reference	**Methodology**	**Limitations**	**Findings**	**Future research**
(Evert, 2015)	Design Science Research (DSR)	The scope of the research project is limited to providing appropriate technological support to tutors of practical sessions at the CS department, NMMU alone. Thus, the results of the evaluation cannot be generalised	Tutors, students and lecturers found the tablet PC application useful and supportive. Tutors were pleased with the user interface, interaction and navigation while participating students agreed that the tool was useful in allowing tutors to answer questions easily, thereby allowing them to complete their work with ease	The tablet PC tool can also be extended to - cater for visualisation in form of videos - enhance its current features such as the ability of students to view FAQ from other technological devices e.g. desktop computer, mobile phones etc. - make it more interactive between tutors and students The inclusion of multiple lecturer participants to determine their opinion of the lecturer chat application could be a benefit to the extension of study
(Wang et al., 2011)	DBR	Need for generalisation of results.	The system had a positive impact on student's attitude towards online learning	The findings of the study give a platform for further exploration with the system to determine its impact on reducing cognitive load and improving self-regulated learning process
(Scarpato, Maria & Pazienza, 2012)	DBR	Most existing knowledge-based visualisation applications work only on specific domains/tasks and thus cannot be generalised. Also, there is lack of automatisation in the process of visualisation	Knowledge based visualisation approaches are associated with the following problems: - Graph-based scalability - Faceted browsing - Domain-specific - Widget-based	The SAGG system model could be - explored to combine several configuration files to generate more complex GUIs and possible specify the interrelationship between them - expanded to cater for more functions
(Eppler & Burkhard, 2004)	Case study	- Domain specific - Risk of possible distortion of reality through misinterpretations	KV presents an avenue to: - create new knowledge and enhancing innovation - solve predominant knowledge-related problems in organisations - be used as an effective strategy against information overload	The following areas need to be investigated: - a comprehensive framework that focuses on knowledge-intensive visualisation is needed - how complementary visualisation can be of benefit - potential negative effects in authentic application contexts

Reference	Methodology	Limitations	Findings	Future research
(Van Biljon & Renaud, 2015b)	Faded-struts	KV is not without designer/user induced risks which can ultimately affect the cognitive, emotional and social human aspects of the communication process	Learners are often times the consumer of visualisation as against being the producers. There is need for them to become active participants in the creation of visualisation in order to improve self-regulated learning	Actively engaging learners in creating KV
(Azzouza, Azouaou & Ghomari, 2010)	DBR	Cognitive overload	The use of ontology-driven visual cartographies can aid knowledge localization and also enable the processing of large collection of web pages within a short period of time	-
(Ahmad, Ahmad & Rejab, 2011)	Exploratory research	Most of the knowledge transferred to learners is in tacit form and difficult to externalise. Also, the use of conventional teaching materials such as lecture notes, or slide presentations is not sufficient to increase student's understanding	The study reveals that KV is one of the approaches to convert lecturer tacit knowledge to student explicit knowledge in teaching and learning process	The conceptual model will be reviewed based on findings of the initial test.

From Table 3.3, it will be observed that the prominent design methodology in KV is that of DBR. In addition, the characteristics of DBR as stated in Table 2.3 made it the design methodology of choice for this study. Other methodologies used were action research, case studies, faded-struts and exploratory research.

A common limitation to KV as observed from the SLR is that of being domain specific and thus difficult to be generalised. In addition, there is the risk of possible distortion of reality through misinterpretations.

Findings include (but are not limited to) the use of KV to: improve learning abilities; improve communication and interaction around cognitive processes; improve learners' attitudes towards learning. A relevant finding is using KV as one of the approaches for converting lecturer tacit knowledge to student explicit knowledge. These findings can be correlated with those of this study, stating that KV can be argued to have improved knowledge acquisition as shown in Table 5.3. However, this is beyond the scope of this study.

Suggested future research includes (but are not limited to): application of visualisation methods in learning; extending findings to new domains; enhancing the features of visualisation tools; further exploration on the use of KV to reduce cognitive load and improve self-regulated learning processes; and actively engaging learners in creating KV. For this study, the application of KV in teaching and learning on one hand, and making learners co-creators of their learning process, was explored.

3.3 Human computer interaction (HCI) and visualisation

In this section, HCI and visualisation are discussed, specifically, the definition of the two terms and the impact of HCI on visualisation.

3.3.1 Human computer interaction (HCI)

Human computer interaction (HCI) is a multi-disciplinary field (Dix, Finlay, Abowd & Beale, 2004; Blackwell, 2015), whose main focus in systems design is rooted in computer science. HCI can therefore be described as the direct or indirect communication between a user (i.e. an individual, a group of people, or a sequence of people in an organisation etc.) and a computer (i.e. any technology ranging from the general desktop computer, to a large-scale computer system, a process control system or an embedded system) (Dix et al., 2004; Holzinger, 2013). It can also be defined as "a discipline concerned with the design, evaluation, and implementation of interactive computing systems for human use, and with the study of major phenomena surrounding them" (Preece et al., 1994:20).

From the above definitions, it can be inferred that HCI has three fundamental components which are: *the human* (an individual or group of users); *the computer* (technological interface); and *the interaction* (direct or indirect communication between the user and the technological interface) (Draganova & Doran, 2013; Frey, Muhl, Lotte & Hachet, 2013) .

3.3.2 Visualisation

Manovich (2010) defined visualisation as the conversion of measurable data into a visual representation, emphasizing summarisation and reduction. Visualisation entails the use of spatial (present in a geographical space or horizon) and non-spatial variables (i.e. numbers, characters or logical types) to represent data in a manner that reveals its patterns and relations (Chen, Ebert, Hagen, Laramee & Liere, 2009; Munzner, 2009; Manovich, 2010). The history of visualisation by Yusoff, Katmon, Ahmad and Miswan (2013) shows how visualisation has evolved from scientific and computing visualisation in the 80s, to data and information visualisation in the 90s and, recently, KV has been added (as shown in Figure 3.2). The evolution of technology has allowed visualisation to be used for educational purposes. For the scope of this research, the focus will be on how learners can use KV to construct, demonstrate and internalise the knowledge that is being transferred to them.

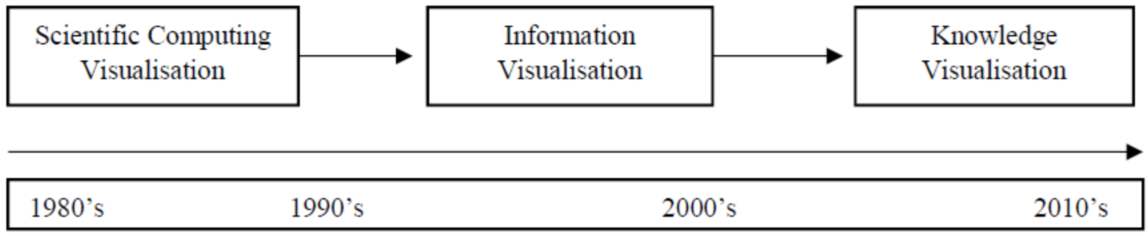


Figure 3.2: Chronology of visualisation (Yusoff et al., 2013)

3.3.3 Impact of HCI on visualisation

Information visualisation systems have two main components: *representation* (i.e. the mapping from data to representation and its rendering on the display in the field of computer graphics) and *interaction* (dialog between the user and the system in the field of HCI) (Yi, Kang, Stasko & Jacko, 2007; Elmqvist, Vande Moere, Jetter, Cernea & Reiterer, 2011). The term 'interaction' correlates with the human to technology communion which is a core value of HCI as explained in section 3.3.1. Information visualisation shares some similarities with KV (Table 3.4 in section 3.4). For these reasons, therefore, HCI has a significant impact on the implementation of KV, particularly on mobile technologies, whereby learners can interact with their visualisation in real time, changing parameters, and seeing the effect (Dix et al., 2004).

Ongoing investigations in HCI such as usability (how well the user can work with the device), cognitive concerns (how the person understands the functionality of the machine), and interface design (how well the device is able to communicate its abilities to the human user), etc. (Jones & Mouloua, 2005; Johnson, 2014), in relation to information and knowledge visualisation applications, can offer new opportunities for engaging learners in design and production activities (Sorapure, 2010).

For this research, one of the foci was the selection of an application on digital devices based on HCI usability principles (from literature) that can be used in implementing KV. These principles are discussed in section 3.7.3.

3.4 Information and knowledge visualisation

The terms *data, information* and *knowledge* are often used interchangeably in a conflicting manner (Chen et al., 2009; Meyer, 2010; Liew, 2013). However, for the purpose of this study, their meaning in the discipline of computer science and in relation to visualisation is given below:

- *Data*: raw unorganised facts collected together without context or interpretation (Meyer, 2010; Baskarada & Koronios, 2013; Vinay, 2018). It can be quantitative or qualitative (Bourgeois, 2018).
- *Information*: aggregated data that contains relevant meaning that can be used to reveal patterns or insights into the data for decision making (Baskarada & Koronios, 2013; Liew, 2013; Van Biljon & Renaud, 2015a). According to Meyer (2010), information answers questions like ”who?”, ”what?”, ”where?”, ”why?” or ”when?”.
- *Knowledge*: data and/or information that have been organised and cognitively processed to convey understanding (Meyer, 2010; Baskarada & Koronios, 2013). Furthermore, Liew (2013) and Meyer (2010) explains that knowledge resides within the mind or in the brain.

According to Mazza (2009), the term “information visualisation” was coined at the end of the 1980s by the researchers of Xerox PARC in order to recognise a new discipline concerned with the creation of visual artefacts aimed at amplifying cognition. Information visualisation can also be referred to as the interdisciplinary field which is traditionally viewed as a set of methods concerned with the visual representation and analysis of complex data sets in ways that enhance understanding (Ward, Grinstein & Keim, 2010; Vande Moere & Purchase, 2011). In addition, Sindiy, Litomisky, Davidoff and Dekens (2013) defined information visualisation as the study of (interactive) visual representations of abstract data, both numerical and nonnumerical, to reveal patterns in data that would be otherwise difficult to find. The implementation of information visualisation often requires high-level cognitive functioning which has been exploited to varying degrees in interaction design and analysis by the HCI and Human Factors and Ergonomics communities to enable induction of insight, reasoning, and understanding (Patterson, Blaha, Grinstein, Liggett, Kaveney, Sheldon, Havig & Moore, 2014).

According to Yusoff et al. (2013), KV is the act of representing complex concepts and data by using graphics and animations, in ways that people have not seen before, in order to aid knowledge transfer and creation. Zhang et al. (2008) and Burkhard (2004) explain KV as the act of exploring the use of visual representations such as graphs, diagrams, drawings, sonographs etc. to enhance knowledge creation and transfer between at least two people. For Bertschi et al. (2011), it is a process that entails various steps such as gathering, interpreting, developing, understanding, designing and sharing information. Eppler (2011) relates the term to the use of graphics to create, integrate and administer knowledge. In summary, KV entails the creation of knowledge, using available visual resources, in a manner that is understandable and communicable to others.

3.4.1 Similarities between information visualisation and knowledge visualisation

Information visualisation and KV complement one another and have similarities as they centre around visual representations. Table 3.4 below shows some similarities between the two terms.

Table 3.4 Similarities between information visualisation and knowledge visualisation (adopted from Van Biljon, 2012)

Information visualisation	Knowledge visualisation	Reference
User-centred design	Know your data, know your audience	(Burkhard, 2005a; Figueiras, 2014)
Overview first, zoom in and filter, then show details on demand Selective omission i.e. Fisheye menus	Focus and context Don’t distract your audience	(Burkhard, 2005b; Heer, Shneiderman & Park, 2012; Burigat & Chittaro, 2013)
Be consistent	Be consistent and avoid decoration	(Ferreira, 2012; Mazumder & Das, 2014)
Affordance: recognition-based approach rather than recall	Use natural representations	(Burkhard, 2005b; Sivaji, Abdullah & Downe, 2011; Haroz, Kosara & Franconeri, 2015)
User satisfaction	Motivate your audience	(Bai, White & Sundaram, 2012; Yusoff et al., 2013)

Table 3.4 above and literature show that both forms of visualisation emphasise the need for the designer to:

- Understand the data domain and for whom the visualisation is intended (Ma et al., 2012; Figueiras, 2014; Antonova, 2016).
- Present a concise image (Heer, Shneiderman & Park, 2012; Burigat & Chittaro, 2013).
- Use relevant elements (Ware, 2012a; Bresciani & Eppler, 2015).

- Associate visualisation with the real-world (Haroz, Kosara & Franconeri, 2015; Borkin, Bylinskii, Kim, Bainbridge, Yeh, Borkin, Pfister & Oliva, 2016).
- Enhance learning engagement (Bai, White & Sundaram, 2012; Yusoff et al., 2013).

3.4.2 Difference between knowledge visualisation and information visualisation

Both KV and information visualisation have their core values in the creation of visual images. Although the two concepts overlap in their common objective to offer insights to the end-user (Chen, 2010), Van Biljon & Renaud (2015) note that the primary aim of KV is *knowledge transfer* whereas that of information visualisation is to support *pattern identification*. In addition, information visualisation refers to a computer-generated interactive visual representation while KV is not necessarily computer generated nor interactive (Chen, 2010; Sorapure, 2010; Bertschi et al., 2011). Of note is the advancement of Information and Communication Technology (ICT) which has empowered KV users with limited drawing skills to comfortably create conceptual visualisations (Bertschi et al., 2011).

Table 3.5 below is an excerpt from Van Biljon & Renaud (2015), itemising the differences between KV and information visualisation. These differences are drawn from the two visualisations' perspective; goal, or aim (Eppler & Burkhard, 2007; Elmqvist & Fekete, 2010); benefit, or gain (Yi et al., 2007; Sindiy et al., 2013); content (Eppler & Burkhard, 2007; Meyer, 2010); the question answered (Antonova, 2016); recipient, that is for whom the visualisation is intended (Burkhard, 2005b); and influence, or their effect (Hou & Nie, 2009).

Table 3.5: Differences between information and knowledge visualisation (Van Biljon & Renaud, 2015b)

	Information visualisation	Knowledge visualisation
Goal	Supports exploration of large amounts of data and knowledge creation	Ease knowledge transfer; Creation of new knowledge
Benefit	Identification of patterns, exploration of large data sets	Augmenting knowledge transfer between individuals; Communicating knowledge
Content	Explicit data such as facts and numbers	Experiences, insights, instructions, assumptions
Answer Question	What	Why, Who, How
Recipients	Data Explorer, Pattern spotter	Knowledge workers
Influence	Data analysis, Data exploration	Knowledge transfer
Example	Depiction of an author's research areas to differentiate topics 	Representation of the relationship between data, information and knowledge 

3.4.3 Burkhard's knowledge visualisation framework

Burkhard (2005) presents a KV framework made up of four main perspectives which are: a *Function type* (depicts why a visualisation type should be used), *Knowledge type* (elucidate on the nature of the content), *Recipient type* (illuminates the different backgrounds of the recipient/audience) and the *Visualisation type* (structures the main visualisation types according to their characteristics). This can be summarised in the Figure 3.3:

FUNCTION TYPE	KNOWLEDGE TYPE	RECIPIENT TYPE	VISUALISATION TYPE
Coordination	Know-what	Individual	Sketch
Attention	Know-how	Group	Diagram
Motivation	Know-why	Organisation	Image
Elaboration	Know-where	Network	Map
New Insight	Know-who		Object
			Interactive Visualisation
			Story

Figure 3.3: Knowledge visualisation framework (Burkhard 2005:58)

The objective of this study required learners to create visual representations with the aim of demonstrating knowledge acquisition while transferring and creating knowledge. To achieve this, Burkhard's KV framework was considered in this study as explained in the section 3.4.3.1-3.4.3.4.

3.4.3.1 Function type perspective

KV augments the process of knowledge acquisition and learning (Antonova, 2016) and should be considered because it:

- Helps learners' motor coordination while conveying information.
- Allows learners to be aware and conscious of visual representations created thus captivating their attention.
- Improve learners' retention of knowledge.
- Inspires and stimulates viewers.
- Gives more details on visual images created and
- Supports learners' understanding: It can aid the augmentation of learners' knowledge acquisition (Anne & Division, 2003).

For this study, the function perspectives applicable are: motor coordination; improvement of learners' knowledge retention; and support of learners' understanding.

3.4.3.2 Knowledge type perspective

The intent and purpose of the content to be visualised plays an important role when visualising. For this research, learners were asked to give a diagrammatic representation of how rockets are launched. But, before creating their images, they had to answer these questions: *what* is known about rocket launching? (e.g. concepts, facts); *how* the knowledge will be visualised (e.g. procedures, processes); *why* visualising is used (e.g. process flow, decision points, causes); *where* to obtain general knowledge on rocket launch (e.g. knowledge sources) and; *who* creates the visualisation and for whom (e.g. teachers, learners).

3.4.3.3 Recipient type perspective

For knowledge to be transferred, the cognitive background of the recipient/audience plays a major role in determining the right visualisation method to be adopted (Bertschi et al., 2011; Antonova, 2016). For this study, the end users were fellow learners (for the purpose of knowledge transfer) and teachers (to demonstrate their knowledge acquisition).

3.4.3.4 Visualisation type perspective

The visualisation type perspective explains how designers (in this study, learners) use different visualisation types e.g. sketches, diagrams, images, maps, objects, interactive visualisations, and stories to transfer knowledge (Burkhard, 2005b). According to Eppler and Burkhard (2004): heuristic sketches can help learners quickly visualise an idea and support their reasoning while interpreting their visualisation; conceptual diagrams can aid learners in exploring structural relationships amongst various parts of the visualisation created, further helping with minimizing complexity, and therefore amplifying cognition; and scientific charts can help learners show the relationship between scientific knowledge. For this study, learners made use of sketches, diagrams and images for their visualisation.

3.5 Pitfalls of knowledge visualisation

There are probable risks and common mistakes committed while creating or interpreting a visualisation and, therefore, the need for guidelines (Van Biljon, 2012; Bresciani & Eppler, 2015). The following sub-section dicusses some of the common pitfalls of KV.

3.5.1 Complexity

Complexity is the state, or quality, of being intricate, or complicated, or difficult to understand. According to Huang, Eades & Hong (2009), there are various factors that may determine the degree of complexity that can affect visualisation. These are:

Domain complexity

Domain complexity is defined as the degree of interdependencies between knowledge domains (Yayavaram & Chen, 2013). Different visualisations are required when representing domains with different data formats and contents, and this can put a constraint on the requirements necessary for specific visualisations.

Data complexity

This includes the number of objects in the data (Baumeister & Freiberg, 2011), attributes of the objects, and the relationships between them.

Task complexity

Liu and Li (2012) explained that task complexity is an important task feature that affects and projects human performance and behaviours. According to Kyndt, Dochy, Struyven and

Cascallar (2011), task complexity can be described as the learner's perception of how complex a task is, or the cognitive demands the task will place on them. Some of the task characteristics that may influence the complexity of a task are: structure of the task; number of elements; requirements imposed by the task; availability of planning time; and prior knowledge (Kyndt et al., 2011; Liu & Li, 2012).

Visual complexity

A visualisation can be visually complex when it contains dense perceptual features (Pieters, Wedel & Batra, 2010). According to Huang, Eades & Hong (2009), visual complexity entails how visual elements and their spatial distribution are visually represented and how well their structural relationships match their natural structural links.

Demographic complexity

This includes motivation, age, gender, cognitive skills, domain knowledge and mental status.

3.5.2 Oversimplification and ambiguity of meaning

Abstraction of data during KV can lead to oversimplification and ambiguity (inexactness) of meaning (Bertschi et al., 2011). Adding more information to KV can either increase or decrease the ambiguity of the images produced (Rodil et al., 2011). In addition, sacrificing features of data in favour of graphical elegance can lead to oversimplification (Womack, 2014; Becheru & Popescu, 2017).

3.5.3 Size of dataset

Designers of KV may find it difficult to manage and process a large data set within a specific period of time and this may compel the designer to focus on specific parts of the visualisation at each point in time (Baumeister & Freiberg, 2011; Manovich, 2011).

3.6 Knowledge visualisation principles

Design principles from the field of information and knowledge visualisation were extracted from literature using the inclusion and exclusion criteria listed in Table 3.1. These search criteria included: knowledge/information visualisation as a primary condition; an identifiable learner level (all learner levels were admissible); knowledge/information visualisation in the context of teaching and learning in the field of educational and computer science; and papers published between January 2010 and December 2017. The principles are listed in Table 3.6, a matrix table that summarises KV principles which can be used to improve images produced for knowledge representations. These principles answer the first research question (RQ_1) that is: *What are the existing knowledge visualisation principles for teaching and learning?*

In Table 3.7, the link between HCI usability guidelines and KV principles is established, leading to the usability-based knowledge visualisation guidelines artefacts developed for this study. In the table, the symbol '✓' identifies KV criteria related to usability guidelines which are subsequently used in creating usability-based knowledge visualisation guidelines for this study. The guidelines relevant to this study as noted in the table are: Abstract (or compress) the knowledge, Easy to understand, Know your data, Clarity, Use natural representations, Legend, Use of colours, Avoid decorations, Relationship between concepts clearly shown, Simplicity and Clear boundaries.

Table 3.6: Knowledge visualisation principles for teaching and learning from literature

	Knowledge visualisation criteria	Description	Author(s)
1	**Abstract (compress) the knowledge**	Extracting essential components and their relationships from a body of knowledge	(Aigner, Rind & Hoffmann, 2012; Scarpato, Maria & Pazienza, 2012; Kumar, 2016; Heer, Shneiderman & Park, 2012; Mengis & Eppler, 2012)
2	**Present overview and details**	'overview' gives a contextual view of the field while the 'detail' gives more information about a part of the overview	(Burigat & Chittaro, 2013; Ware, 2012; Heer, Shneiderman & Park, 2012)
3	**Consistency**	The use of visual elements such as colour, symbols, shapes etc. should be the same for the same kinds of information	(Bresciani & Eppler, 2015; Ware, 2012)
4	**Easy to understand**	Presenting visualisation in a clear, comprehensive way makes it easy to understand, such that little previous knowledge of the content is required.	(Figueiras, 2014)(Zhou, Yin & Wang, 2011; Figueiras, 2014)
5	**Know your data**	A designer must first understand and explore the data domain in order to create images that are meaningful and relevant	(Ware, 2012; Figueiras, 2014)
6	**Clarity**	The use of defined symbols to avoid ambiguity	(Bresciani & Eppler, 2015; Gavrilova, Leshcheva & Strakhovich, 2015)
7	**Know your audience**	The designer should consider for whom the visualisation is intended e.g. an individual, a group, a network etc.	(Ma et al., 2012)
8	**Use natural representations**	Associating visualisation with the real world allows a recognition-based approach to interpreting images instead of one that requires recall	(Meyer, 2010; Ware, 2013; Haroz, Kosara & Franconeri, 2015; Borkin et al., 2016)
9	**Legend**	An accompanying item which: provides detailed explanations on symbols used, can become a control panel for making changes and provide multiple views on the data.	(Heer, Shneiderman & Park, 2012; Graham, Milligan & Weingart, 2016; Hall & Virrantaus, 2016)
10	**Use of colours**	To: specify a format that is applicable to a set of instances, differentiate relationships, beautification, grouping, mapping and classifying images.	(Scarpato, Maria & Pazienza, 2012; Zhi & Su, 2015; Hullman & Diakopoulos, 2011; Ware, 2012)
11	**Avoid decorations**	The use of irrelevant elements may distract the audience from the content of the topic	(Haroz, Kosara & Franconeri, 2015; Bresciani & Eppler, 2015)
12	**Relationship between concepts clearly shown**	Relationship between concepts can be illustrated using links	(Wang et al., 2011; Gavrilova, Leshcheva & Strakhovich, 2015)
13	**Motivate audience**	To enhance learning engagement	(Bai, White & Sundaram, 2012; Yusoff et al., 2013)
14	**Simplicity**	Minimizing the number of concepts in each level of visualisation to 7±2 objects	(Gavrilova, Leshcheva & Strakhovich, 2015)
15	**Dual coding**	Using both textual and visual representation to process information.	(Bresciani, Ge & Niu, 2014; Marchese & Banissi, 2012; Ware, 2013b)
16	**Clear boundaries**	To help with navigation and enclosing knowledge within a specific domain	(Diakopoulos, Kivran-Swaine & Naaman, 2011)

Table 3.7: Link between usability guidelines and KV principles

	Knowledge visualisation criteria	HCI usability guidelines related to KV criteria	Relevance to this study
1	**Abstract (compress) the knowledge**	Detect relevant and irrelevant information (Ssemugabi & De Villiers, 2010; Ferreira, 2012)	✓
2	**Present overview and details on demand**	Easy navigation and support of search task (Burigat & Chittaro, 2013)	x
3	**Consistency**	Combination of distinct concepts and ideas; adherence to standards (Norman & Nielsen, 2010; Ssemugabi & De Villiers, 2010; Ferreira, 2012)	x
4	**Easy to understand**	Recognition rather than recall; Aesthetics and minimalism in design (Ssemugabi & De Villiers, 2010)	✓
5	**Know your data**	Awareness of previous and related work (Ferreira, 2012)	✓
6	**Clarity**	Clarity of goals, objectives and outcomes (Ssemugabi & De Villiers, 2010)	✓
7	**Know your audience**	Designers must understand their audience, their needs, abilities, interests, and expectations (Ferreira, 2012)	x
8	**Use natural representations**	Match between the system and the real world (Ssemugabi & De Villiers, 2010)	✓
9	**Legend**	Context meaningful to domain and learner (Ssemugabi & De Villiers, 2010)	✓
10	**Use of colours**	To distinguish a particular subset or branches (Gavrilova, Leshcheva & Strakhovich, 2015)	✓
11	**Avoid decorations**	Aesthetics and minimalism in design to avoid distraction (Ssemugabi & De Villiers, 2010)	✓
12	**Relationship between concepts clearly shown**	Attributes and relationships among concepts (Ferreira, 2012)	✓
13	**Motivate audience**	Learner motivation, creativity and active learning (Ssemugabi & De Villiers, 2010)	x
14	**Simplicity**	Simplicity of site navigation, organisation and structure; Removal of unnecessary complexity (Lidwell, Holden & Butler, 2010; Ssemugabi & De Villiers, 2010; Ware, 2012c)	✓
15	**Dual coding**	Using both textual and visual representation to process information (Bresciani, Ge & Niu, 2014)	x
16	**Clear boundaries**	Navigation and enclosing knowledge within a specific domain (Diakopoulos, Kivran-Swaine & Naaman, 2011)	✓

3.7 Digital support for knowledge visualisation in teaching and learning

KV entails the creation of transferable knowledge, using available visual resources that may be computer or non-computer based. The computer based visual resources amongst many can be in the form of mobile applications, that is technological platforms, that are developed for and used on digital devices (Barati & Zolhavarieh, 2012). The application can then be used as a platform on which KV is implemented. According to Schnotz & Kürschner (2008) and Antonova (2016), the use of multimedia and KV can play an important part in learning and knowledge acquisition as visual information can conveniently be digitalised, stored and shared on digital devices, and thus, have the potential of reaching a wider audience.

For this study, both the computer and non-computer based visual resources were used. The non-computer based comprised of the presentation of KV on plain paper while the computer based required the implementation of KV using digital devices.

Section 3.7.1 discusses some of the mobile technology on which the visual images from the implementation of KV can be produced. In addition, their properties are explained in the mobile learning context. Section 3.7.2 is a discussion of the mobile application platform on which KV was implemented for this study.

3.7.1 Mobile devices and mobile learning

A mobile device is a portable computing device that integrates multimedia functions (Westlund, 2008). It is an electronic gadget that has the following general components and capabilities: Wi-Fi connectivity, a battery for powering the device, physical or onscreen keyboard, portability, touch-screen interface (in most cases), a virtual assistant, ability to download apps, wireless operations etc. (Jacob & Issac, 2008; Kroski, 2008; Gikas & Grant, 2013). Mobile computing devices can provide educational opportunities for students to access course content, as well as interact with instructors and fellow student wherever they are located (Shih & Mills, 2007; Cavus & Ibrahim, 2008; Kukulska-Hulme & Shield, 2008; Richardson & Lenarcic, 2008; Nihalani & Mayrath, 2010). These facile interactions are made even more accessible by using mobile devices in conjunction with social media, plus free web tools that allow for communication and can enhance learning (Rodriguez, 2011).

Examples of digital devices on which KV can be implemented are cell phones, tablet computers (e.g. iPads), E-books, laptops, smartwatches. Given the ease of and accessibility of mobile learning, educational formats are no longer bound by traditional locations as learning can take place anywhere at any time (Wilson & Aagard, 2012).

Klopfer, Squire and Jenkins (2002) and Weisberg (2011) identified the following properties of mobile devices that produce unique educational experiences. These are:

- *Portability:* the dimension of the mobile devices in terms of size and weight makes them easy to move around.
- *Social interactivity:* interaction with other learners for sharing information and collaboration.

- *Context sensitivity:* mobile devices can use the context information such as location, time and environment to provide context-aware resources.
- *Connectivity:* mobile devices can be connected to other devices and networks using wireless technologies.
- *Affordability and ubiquitous accessibility:* mobile devices put web access and 'high-spec' functionality in the hands of more users than any other digital technology.
- *Individuality:* learning can be personalized to suit individuals' needs and preferences.

For the purpose of this study, the digital device used to conduct the research were laptops which were provided to each learner to implement their KV.

3.7.2 Mobile applications

There are several existing mobile applications that can be used for KV. Examples include Microsoft tools (i.e. Visual Studio, Paint, PowerPoint, Excel, Hololens etc.), Google drawing, Padlet, Cmap, Maple, Scilab, LibreOffice, to mention a few. For the purpose of this research, the two mobile applications that were considered were LibreOffice Draw and Padlet. These applications were selected based on their compliance with criteria from literature such as their ease of availability, installation requirements, aesthetics, and, as proposed by Botha, Herselman and Van Greunen (2010) and Strakhovich (2014), learners' ability to access additional services on their devices. While these criteria may cover some important aspects of quality, the two mobile applications were still subjected to usability evaluation centred on usability principles for selecting KV tools as shown in Table 3.9.

LibreOffice Draw is a vector graphics drawing tool that can be used to create a wide variety of graphical images. It is a free and open source tool whose functions include (amongst many): layer management, snap functions and grid-point system, dimensions and measurement display, connectors for making organization charts, 3D functions that enable small three-dimensional drawings to be created (with texture and lighting effects), drawing and page-style integration, and Bézier curves (Fox & Cleland, 2015).

Padlet is also a free web-based bulletin board where students and teachers can collaborate, reflect, express ideas, and share information for teaching and learning processes (Delacruz et al., 2014; Fuchs, 2014; Zhi & Su, 2015). It is a multimedia-friendly wall that caters for real-time, whole-class participation (Fuchs, 2014).

3.7.3 HCI usability principles for selecting knowledge visualisation tools

HCI usability principles were extracted from literature and used for the selection of the most appropriate KV tool for this study. A usability test was conducted, and the details are presented in Chapter 4. Steps taken for the test conform to those stated by Bastien (2010). The measurement of the HCI principles, that is, the level to which the KV tool complied with the HCI principles, were determined from the analysis of the questionnaire completed by the usability testers. This was necessary in order to select the most appropriate tool for this research to aid learners in showcasing their KV images.

Table 3.8 is a presentation of usability rules or principles extracted from literature, indicating measurable and related principles selected for this study. These usability principles are excerpted from Shneiderman's eight golden rules and Nielsen's ten heuristics, as discussed by Dix, Finlay, Abowd and Beale (2004) and Mazumder and Das (2014).

Table 3.8: HCI usability principles extracted from literature, indicating those selected for this study

Usability principles	Selected usability principles for this study	References
Shneiderman's 8 Golden Rules		(Shneiderman, 2010)
1. Strive for consistency	Consistency	
2. Enable frequent users to use shortcuts	Flexibility	
3. Offer informative feedback	Learnability	
4. Design dialogue to ease closure	-	
5. Offer simple error handling	Effectiveness, Satisfaction	
6. Permit easy reversal of actions	Effectiveness	
7. Support internal locus of control	Learnability	
8. Reduces short-term memory load	-	
Nielsen's 10 Usability Heuristics		(Nielsen, 1994)
1. Visibility of system status	-	
2. Match between system and real world	-	
3. User control and freedom	Learnability, Flexibility	
4. Consistency and standards	Consistency	
5. Help users recognise, diagnose and recover from errors	Effectiveness	
6. Error prevention	Effectiveness	
7. Recognition rather than recall	-	
8. Flexibility and efficiency of use	Flexibility, Efficiency	
9. Aesthetic and minimalist design	-	
10. Help and documentation	Learnability	

Shneiderman's 8 golden rules and Nielsen's 10 usability heuristics were selected because both are seminal authors in the field of HCI and usability testing. The selected usability principles in Table 3.8 are further explained in Table 3.9 below. These usability principles that are relevant for the selection of KV tools answers the second research question (RQ_2), that is, '*Which usability principles are relevant to knowledge visualisation?'*

The list of selected usability principles in Table 3.9 are explained below:

- *Learnability:* This refers to the ease with which learners can learn how to use the application in a minimum amount of time (Dubey, Gulati & Rana, 2012) i.e. the application must be simple, intuitive and require least time to learn.
- *Flexibility:* The KV tool should have an interface that can easily be customized by learners so as to choose that which adapts better to their context (Ssemugabi & De Villiers, 2010; Nassar, 2012).
- *Consistency:* It is expected that the user interface has an unvarying appearance and behaviour to help learners have a smooth user interaction with the tool (Pearson, Buchanan & Thimbleby, 2010; Ssemugabi & De Villiers, 2010).
- *Effectiveness:* The ability of learners to complete their task successfully while avoiding errors (Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012).
- *Efficiency:* The level of physical and mental effort needed to complete a task by learners should be reasonable (Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012).
- *Satisfaction:* The tool should be pleasant to use (Diah et al., 2010).

Table 3.9: HCI usability principles used for selecting knowledge visualisation tools

Usability principles used to inform knowledge visualisation	Authors
Learnability - Easy to use. - New users can easily master the system and begin to use it effectively. - User can easily locate available actions. - Most of the pages have appropriate 'Help' link.	(Burns, 2000; Dünser et al., 2007; Moczarny, 2011; Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012; Menteş & Turan, 2012; Nassar, 2012; Borgo et al., 2013; Babaian, Xu & Lucas, 2014)

Flexibility - Allow user to modify interface to suit their needs. - Offer support for easy modification of images. - Provides 'accelerators' (unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users). - Allow different ways to perform action.	(Dünser et al., 2007; Ssemugabi & De Villiers, 2010; Moczarny, 2011; Nassar, 2012)
Consistency - User interface is consistent in appearance (The same words and symbols are used to refer the same things throughout). - User interface is consistent in behaviour (the same actions are performed the same way, throughout the system). - The same concepts, words, symbols, situations, or actions refer to the same thing/can be done the same way.	(Pearson, Buchanan & Thimbleby, 2010; Ssemugabi & De Villiers, 2010; Moczarny, 2011; Lim, Song & Lee, 2012; Nassar, 2012)
Effectiveness - Offer support to achieve your goal (i.e. complete tasks). - Every icon on a page fulfils a purpose. - Offer support for correcting error successfully.	(Moczarny, 2011; Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012; Menteş & Turan, 2012)
Efficiency - Task can be completed within a reasonable period of time. - Information in the navigational headings is grouped logically. - The tool is capable of allowing users to carry out their work efficiently.	(Moczarny, 2011; Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012; Menteş & Turan, 2012; Babaian, Xu & Lucas, 2014)
Satisfaction - Tool must be easy to use. - Easy to correct errors successfully.	(Dünser et al., 2007; Moczarny, 2011; Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012; Menteş & Turan, 2012)

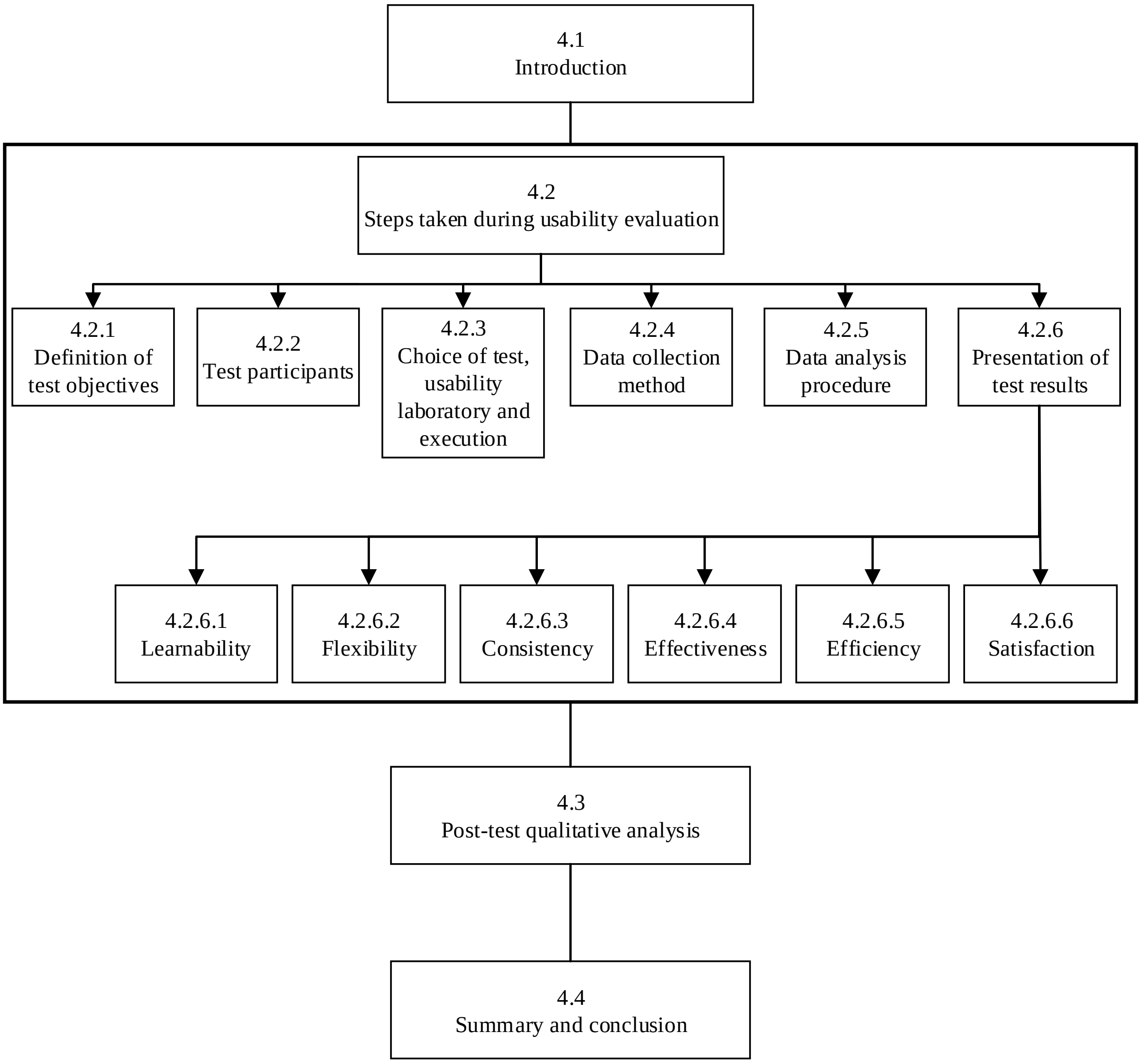
3.8 Summary and conclusion

This chapter provided a literature-based background on the role of HCI principles in implementing visualisation amongst teachers and learners in South African high schools. This included an investigation into KV principles applicable to teaching and learning to answer RQ1, that is: '*What are the existing knowledge visualisation principles for teaching and learning*?' in section 3.6.

Devices such as smart phones, desktop computers, laptops and tablet PCs etc. have emerged as useful tools to educators, students and tutors alike. The interaction of learners with technology is an important factor in selecting that which is most appropriate when considering teaching and learning. The HCI principles considered (Table 3.9) were those related to KV. The study investigated the usefulness of HCI principles' in selecting the most appropriate digital device and application necessary to evaluate the utility of knowledge visualisation principles for improving knowledge presentation and demonstrating knowledge transfer by high school science learners in South Africa.

Using the HCI usability principles identified in this chapter in answer to $RQ_{2,}$ that is, *Which usability principles are relevant to knowledge visualisation*, the next chapter describes the process of evaluating and selecting the knowledge visualisation tools considered for this study.

Map of Chapter 4 (Usability evaluation of knowledge visualisation tools)



Chapter 4 Usability evaluation of knowledge visualisation tools

4.1 Introduction

This chapter addresses the second research question (RQ_2): *Which usability principles are relevant to knowledge visualisation?* Additionally, the process used for selecting the most appropriate KV tool for this study is described in this chapter. To accomplish this, the outcome of the $RO_{2.2}$ is used as guide: To identify usability principles relevant for the selection of visualisation tools was achieved, using the HCI usability principles stated in Table 3.9. The KV tool is the device used for facilitating and demonstrating knowledge transfer. To recap, the HCI usability principles relevant for the selection of the visualisation tool include: Learnability, Flexibility, Consistency, Efficiency, Effectiveness and Satisfaction. These principles were concurrently evaluated by the participants' (usability testers) involvement in the same cycle of testing. The test required the testers to create a diagrammatic representation of how a rocket is launched, using each of the visualisation tools availed to them. Each tool was then analysed and graded based on the aforementioned usability principles. The evaluation method, which encompasses usability testing, post-test questionnaires and observation, was used for testing interactive systems. According to Smuts, Van der Merwe and Loock (2009), it is essential to select the most appropriate KV tool to facilitate knowledge transfer.

The steps taken for the usability evaluation of the KV tools are described in section 4.2, and these include: definition of test objectives; test participants; choice of test, usability laboratory and execution; data collection method; data analysis procedure; and presentation of test results. In section 4.3, the post-test qualitative analysis carried out is discussed and, in section 4.4, the summary and conclusion of the chapter are presented.

4.2 Steps taken during usability evaluation

The usability evaluation was user-based. Participants were asked to complete tasks with the two KV tools selected, namely, Padlet and LibreOffice Draw. The steps taken for the test conform to those stated by Bastien (2010) and these are: definition of test objectives; qualification and recruitment of test participants; choice of test, usability laboratory and execution; data collection method; data analysis procedure; and presentation of test results.

4.2.1 Definition of test objectives

The objective of the usability evaluation was to select the most appropriate KV tool for this study. This was accomplished by analysing the compliancy of the selected tools, Padlet and LibreOffice Draw, to HCI usability principles for mobile applications as stated in section 3.7.3. The level of compliance of the two KV tools to each principle was analysed based on the task the usability testers were assigned to accomplish. A tabular and graphical representation of the outcome of the result for each principle is shown and explained in section 4.2.6.

4.2.2 Test participants

Five usability testers (two females) were selected, each having over 5-years of user-experience with information technology devices. The minimum qualification of the testers is a post matric qualification while three of them have post graduate qualifications. In the pre-survey analysis of the testers, only one participant had heard of LibreOffice Draw and none of them had used the Padlet tool prior to the test. However, they had all used visual images such as graphs, sketches, tables, charts, pictures and animations to represent aspects of their work.

While there is no consensus on the optimal size of participants for usability testing, factors such as personality of participants, time constraint, budget, size of the software product, skill of evaluator, task selection, context of study, complexity of the system type and quality of methodology used to conduct the assessment can have an impact on the estimation of sample size (Alroobaea & Mayhew, 2014; Fox & Cleland, 2015; Cazañas, De San Miguel & Parra, 2017). According to Rubin and Chisnell (2008), it is important to conduct the test with people whose background and abilities have some representation of the target audience. All five participants (usability testers) had a minimum level of education; they were technologically well informed and had used visual images to represent their work. They were, therefore, deemed suitable judges of an appropriate KV tool used for this study.

4.2.3 Choice of test, usability laboratory and execution

A controlled environment was used as a laboratory to carry out the usability test so as to increase the attention span of testers, thus providing considerable information (Carpendale, 2008). Selection of the test environment was based on: test design and measures, ease of communication between participants and evaluator, accessibility to participants, and availability of test materials, as advised by Rubin and Chisnell (2008). In addition to internet access, digital devices (i.e. laptops and tablets) were provided with pre-installed versions of the visualisation tools.

The interaction consisted of the task of creating KV images using the two mobile application platforms. The images were representations of how rockets are launched, a model which can be applied in STEM education. In the process of creating these images, each KV tool was evaluated based on its conformity to the HCI usability principles (as stated in section 3.7.3).

4.2.4 Data collection method

To gather statistical data for the test, questionnaires were used which included:

- **User-profile demographic details** i.e. age, gender, level of education, employment status.
- **Scalar questions:** Based on a numeric scale known as Likert scaling, users were asked to judge the KV tool's compliance against usability principles. For example, users were asked to rate the flexibility of the tool based on 'ease of use' etc.
- **Open-ended questions:** Open-ended questions are designed to encourage participants to be more transparent as far as their knowledge and/or feelings. When compared with close-ended questions, they tend to be more objective and less leading (MediaCollege, 2015). For this study, usability testers were asked, for example, to list additional usability functionalities that could have augmented the tool but had not been included in the questionnaire. The questionnaires were administered to testers after they had interacted with Padlet and LibreOffice Draw, the two KV tools selected for this study. Once the task was finished, they completed the post-test questionnaire to capture their usability perception regarding each tool's compliance with usability principles (as stated in section 3.7.3).

The questionnaire given to testers is included in Appendix D. In addition to the questionnaire administered after the test, the researcher was able to observe the interaction of each tester with each tool during the test. Although sessions were not recorded, observational notes were taken.

4.2.5 Data analysis procedure

The quantitative data from the test was evaluated using statistical analysis and the outcome of the result is stated in section 4.2.6. Qualitative data, derived from observation by the researcher and through open-ended questions, was analysed by the researcher, the results of which are included in sections 4.2.6 – 4.3.

4.2.6 Presentation of test results

The results of the test are now presented by providing a description of the criteria, followed by the results of the evaluation of each usability criteria.

4.2.6.1 Learnability

Learnability, according to Dubey, Gulati and Rana (2012), is the degree to which a mobile application is simple and easy to learn within a short period of time. Literature have shown various factors affecting the ability of an individual to learn, such as: genetics, thoughts, beliefs, environment, health, rate of assimilation, memory, self-efficacy etc. (Van Dinther, Dochy & Segers, 2011; Pritchard, 2013). These factors are not discussed further as they are beyond the scope of this study.

During the test, all participants required assistance in the initial navigation of the tools, with more testers requiring it with LibreOffice Draw than with Padlet. Table 4.1 and Figure 4.1 show the statistical perception of usability testers on the use of Padlet and LibreOffice Draw in relation to their learnability. They show that 80% of the testers agreed that Padlet is easy to use; 60% agreed that new users can easily master the system and begin effective interaction with the tool. Although 60% of the testers strongly agreed that the pages of the LibreOffice Draw application have appropriate 'help' links, an important aspect of learnability according to Dubey, Gulati and Rana (2012), more testers agreed that it is easier to locate available actions on Padlet.

Table 4.1: Learnability evaluation

	The tool is easy to use		New users can easily master the system and begin to use it effectively		User can easily locate available actions		Most of the pages have appropriate 'Help' links	
	Padlet	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**
Strongly disagree							20%	
Somewhat disagree		40%		40%		20%		
Neither agree nor disagree	20%	20%	20%	60%	20%	60%	80%	
Agree	80%	40%	60%		60%	20%		40%
Strongly agree			20%		20%			60%

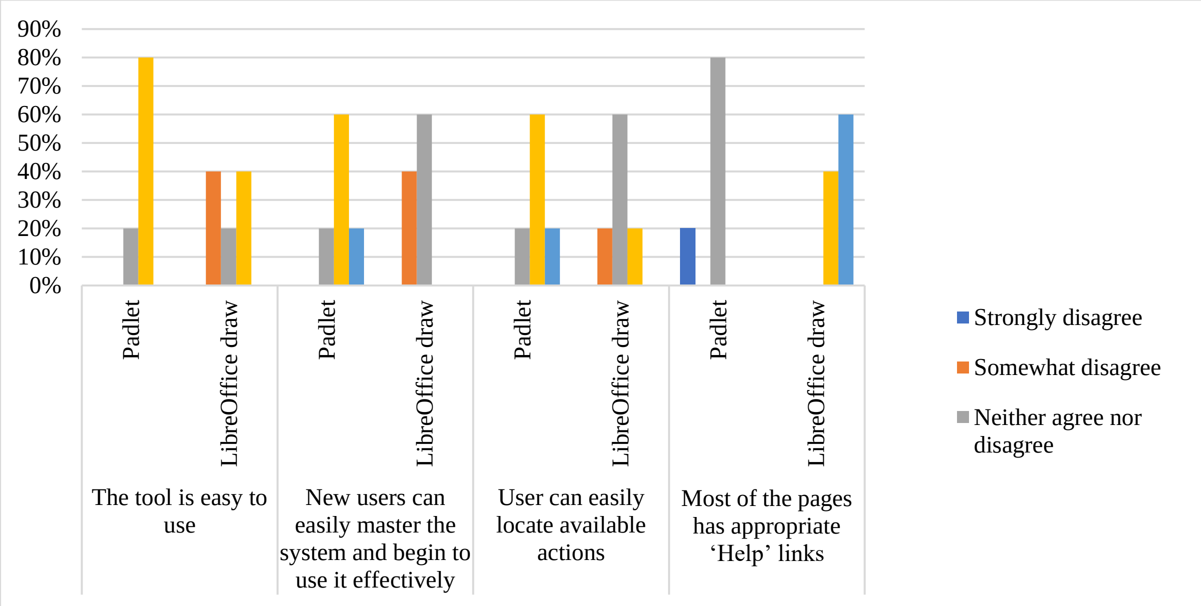


Figure 4.1: Learnability evaluation

4.2.6.2 Flexibility

As explained by Sivaji, Abdullah and Downe (2011), users need to feel in control of the system in order to achieve flexibility in a mobile application design. This can be achieved via the use of accelerators (short-cut keys), icons for interface customization and the availability of different menu options (Nassar, 2012).

However, Lidwell, Holden and Butler (2010) argue that even though flexible designs can perform more functions than specialized designs, they are more complex and generally difficult to use. They attribute these limitations to the complexity and complications associated with the design while attempting to accommodate a larger set of design requirements. In Table 4.2 and Figure 4.2, 60% of the testers strongly disagreed when asked if Padlet makes it easy to modify imported images into the application. In addition, Padlet has predefined interfaces to work with. However, more testers agreed that for expert users, it provides more accelerators which may help in speeding up their interaction. The researcher observed that Padlet provides alternative ways for testers to perform similar actions when compared to LibreOffice Draw.

Table 4.2: Flexibility evaluation

	Allow user to modify interface to suit their needs		Offer support for easy modification of images		Provides 'accelerators' (unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users)		Allow different ways to perform action	
	Padlet	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice draw**
Strongly disagree		20%	60%	20%				
Somewhat disagree	60%		40%		20%		40%	20%
Neither agree nor disagree		20%		20%			20%	20%
Agree	20%	40%		20%	60%	40%		40%
Strongly agree	20%	20%		40%	20%	60%	40%	20%

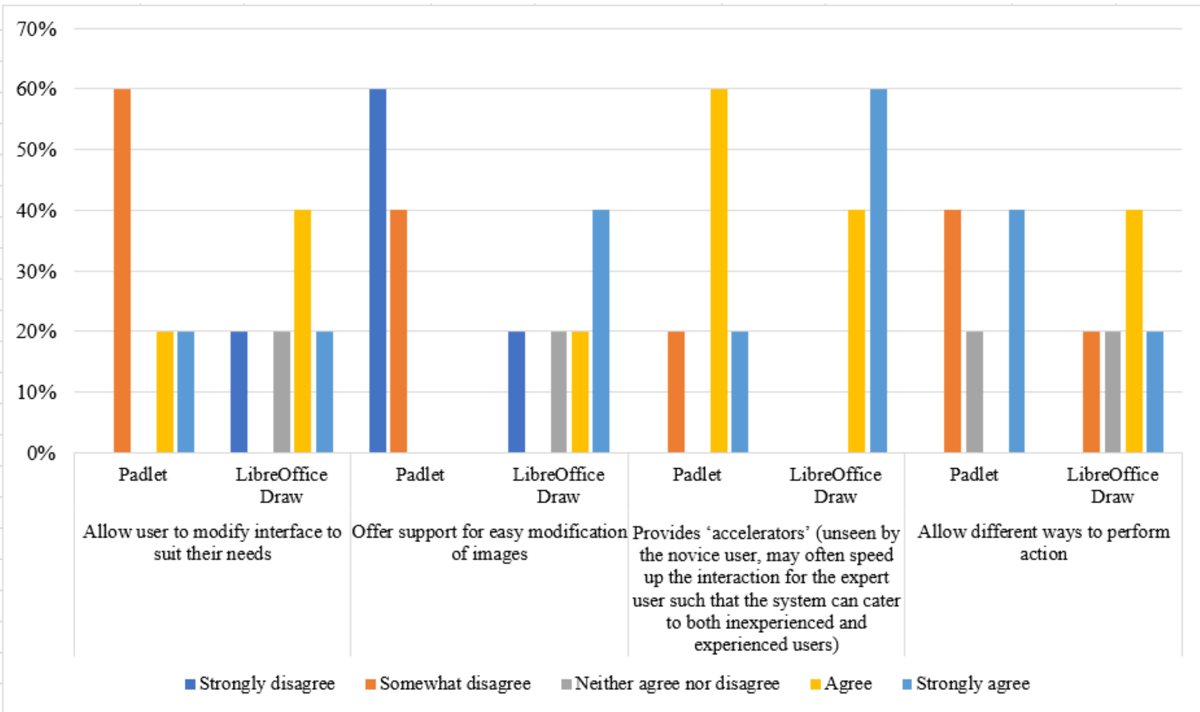


Figure 4.2: Flexibility evaluation

4.2.6.3 Consistency

Pearson, Buchanan and Thimbleby (2010) explain that the interface of a mobile application plays an important role in the smooth user interaction of such applications. They further argue that variation in the appearance of the tool can lead to: bad interaction, low rate of use of the tool, or the user getting confused. In essence, it is necessary to maintain consistency in appearance and behaviour by adhering to common platform standards (Norman & Nielsen, 2010; Ssemugabi & De Villiers, 2010). Norman and Nielson (2010) also note that lack of consistency can threaten the viability of a mobile application.

In Table 4.3 and Figure 4.3, it will be observed that 80% of the testers could not decide whether the user interface of LibreOffice Draw is consistent or not, while 40% agreed and 40% strongly agreed that while using Padlet, the same words and symbols are used to refer to the same things throughout. For both tools, 60% of the testers strongly agreed that the same actions are performed the same way throughout the system, giving credit to consistency in behaviour. In addition, there was no disagreement that the same concepts, words, symbols, situations, or actions refer to the same thing or can be done the same way by both tools.

Table 4.3: Consistency evaluation

	User interface is consistent in appearance (The same words and symbols are used to refer the same things throughout)		**User interface is consistent in behaviour (the same actions are performed the same way, throughout the system)**		**The same concepts, words, symbols, situations, or actions refer to the same thing/can be done the same way**	
	Padlet	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**
Strongly disagree						
Somewhat disagree						
Neither agree nor disagree	20%	80%	20%			20%
Agree	40%	20%	20%	40%	40%	40%
Strongly agree	40%		60%	60%	60%	40%

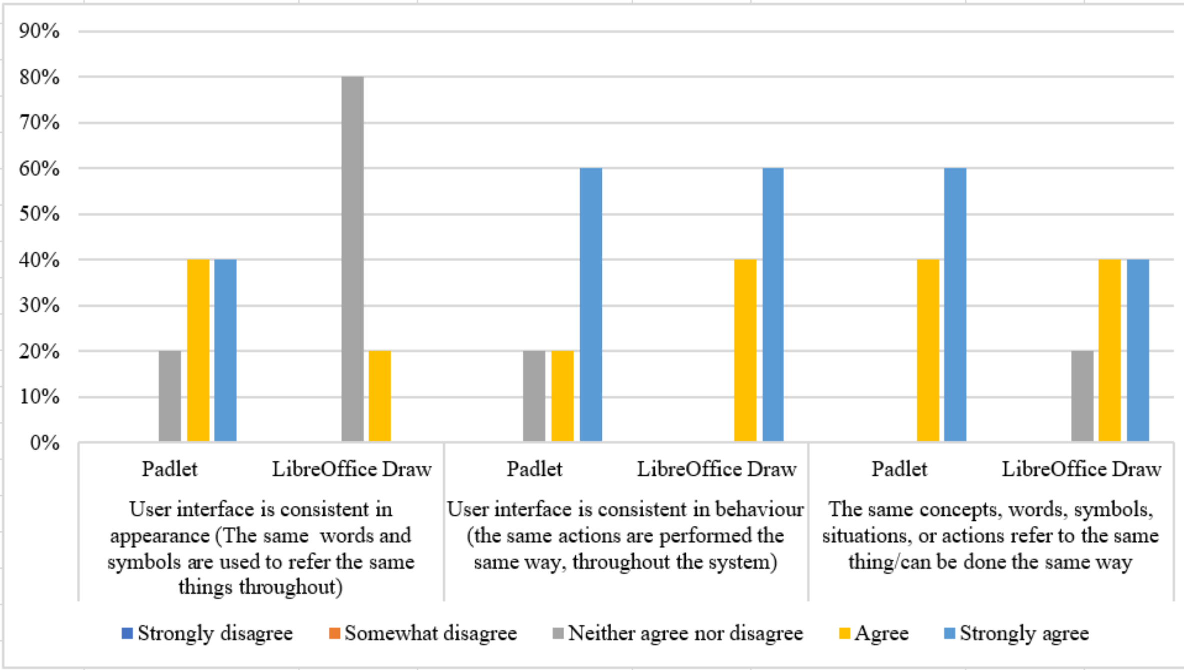


Figure 4.3: Consistency evaluation

4.2.6.4 Effectiveness

The effectiveness of an application is measured by whether a user can complete his or her task successfully with minimal errors (Kainda, Flechais & Roscoe, 2010; Dubey, Gulati & Rana, 2012; Lim, Song & Lee, 2012; Raptis et al., 2013). According to Kainda, Flechais and Roscor (2010), an ineffective system is likely to be abandoned if the user is unable to achieve intended goals.

Testers were required to use the two KV tools (i.e. Padlet and LibreOffice Draw) to create a diagrammatic representation of how rockets are launched. They were allocated thirty minutes per tool to execute the task. About 50% of the testers were able to complete their task within the given time. The researcher noted that each of the testers required assistance while starting up the test, but the frequency reduced once they got acquainted with both KV tools.

Lim, Song and Lee (2012) explain that effectiveness can be achieved when the system meets the following requirements: offer support for correcting errors; icons or menus offer feedback; help information is strategically located. In Table 4.4 and Figure 4.4, 40% of the testers agreed and 40% strongly agreed that Padlet offers support for correcting error successfully when compared to 40% agreeing and 20% strongly agreeing for LibreOffice Draw. In addition, 80% of the testers agreed that while using Padlet, every icon on a page fulfils a purpose compared to 40% for LibreOffice Draw.

Table 4.4: Effectiveness evaluation

	Offer support to achieve your goal (i.e. complete tasks)		Every icon on a page fulfils a purpose		Offer support for correcting error successfully	
	Padlet	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**
Strongly disagree						
Somewhat disagree						
Neither agree nor disagree	60%	60%	20%	60%	20%	40%
Agree	20%	40%	80%	20%	40%	40%
Strongly agree	20%			20%	40%	20%

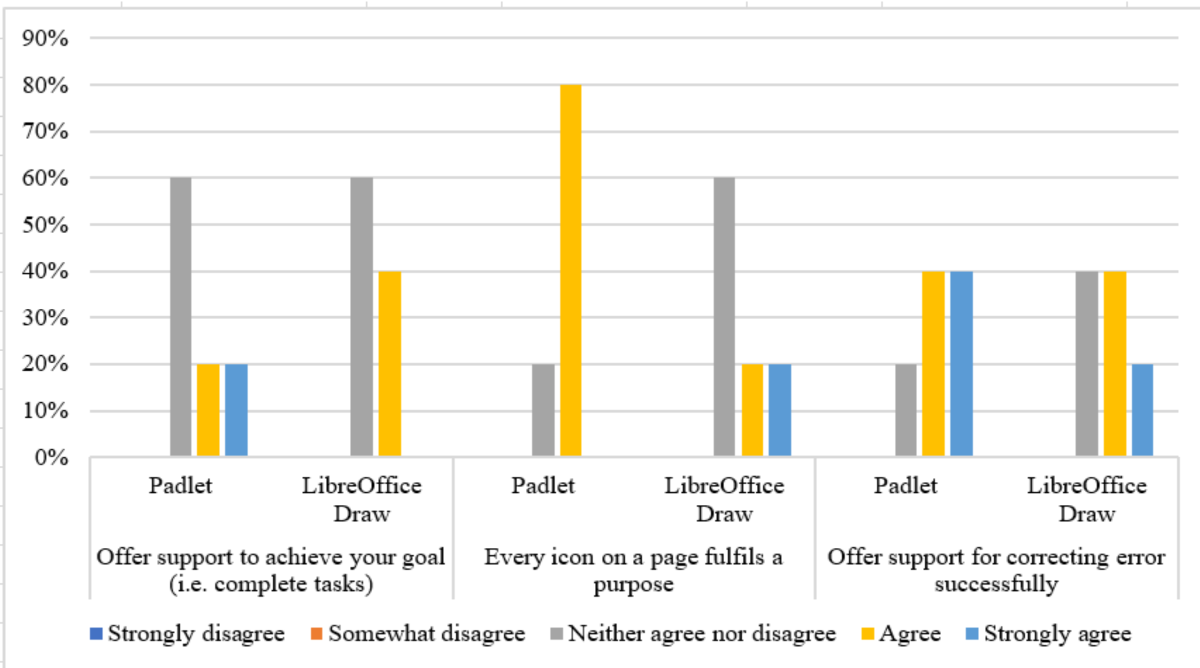


Figure 4.4: Effectiveness evaluation

4.2.6.5 Efficiency

Some design elements associated with efficiency are: convenience of operation, time and memory load minimization (Lim, Song & Lee, 2012). Another factor that has been shown to significantly affect efficiency is the screen size of the mobile application used (Raptis, Tselios, Kjeldskov & Skov, 2013), a topic that is beyond the scope of this study. It should be noted that for this study each tester used the same digital device while testing the two KV tools (i.e. Padlet and LibreOffice Draw).

Table 4.5 and Figure 4.5 show that 20% of the testers disagreed when asked if information in the navigational headings are grouped logically while using Padlet. They also show that 40% agreed and another 40% strongly agreed that the navigational headings for LibreOffice Draw are structured logically. Twenty percent agreed and 40% strongly agreed that LibreOffice Draw is capable of allowing people to carry out their work efficiently when compared to 60% agreeing and 20% strongly agreeing for Padlet. To increase efficiency, some testers suggested that the Padlet menu should be grouped logically.

Efficiency is often measured through task completion times (Naumann & Wechusung, 2008; Kainda, Flechais & Roscoe, 2010; Raptis et al., 2013). The researcher noted that during the test, not all participants were able to complete their task within the allocated time of thirty minutes per KV tool (section 4.2.6.4). While the total time taken to complete each task was not measured, testers were able to give meaningful opinions on each of the HCI usability principles based on each tool used.

Table 4.5: Efficiency evaluation

	The task (diagram) was completed within a reasonable period of time		**The task (diagram) required reasonable amount of effort to complete**		**Information in the navigational headings are grouped logically**		**The tool is capable of allowing people to carry out their work efficiently**	
	Padlet	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**	**Padlet**	**LibreOffice Draw**
Strongly disagree								
Somewhat disagree			60%		20%			20%
Neither agree nor disagree	20%	40%		40%	40%	20%	20%	20%
Agree	40%	60%	40%	40%	40%	40%	60%	20%
Strongly agree	40%			20%		40%	20%	40%

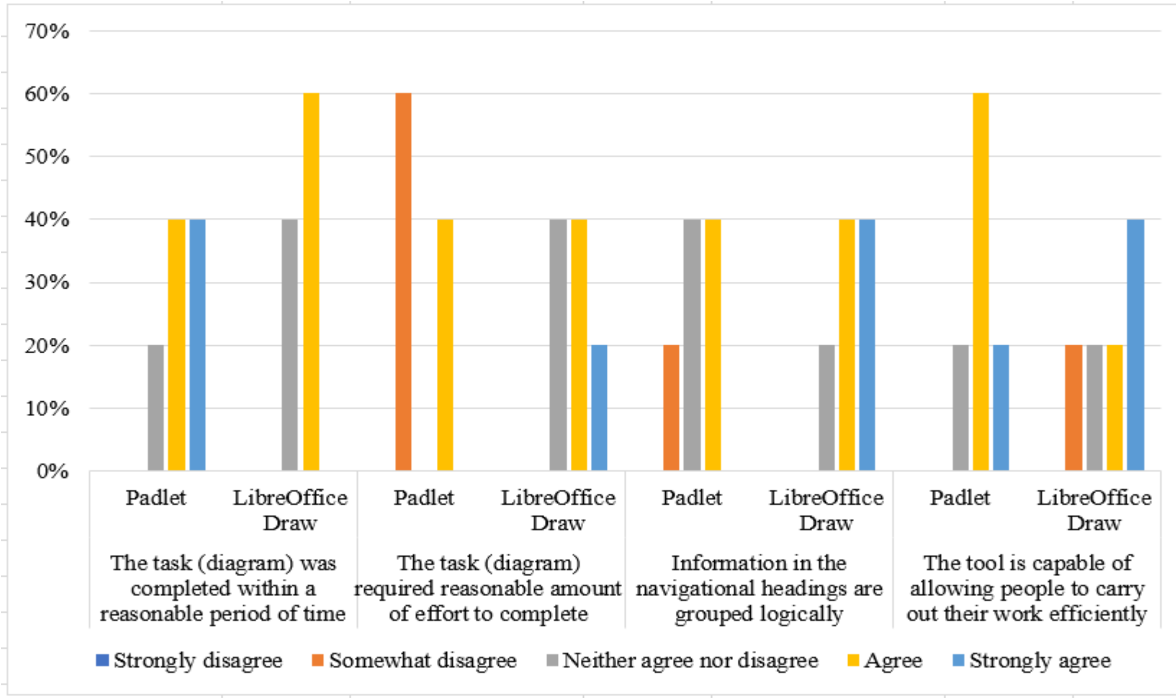


Figure 4.5: Efficiency evaluation

4.2.6.6 Satisfaction

Satisfaction is a measure of a user's feeling about the use of a system (Diah et al., 2010). As a usability principle, satisfaction is a subjective input that cannot be captured using task-based questions. It can, however, be measured using rating scale questionnaires and interviews upon completion of the test (Naumann & Wechusung, 2008; Diah, Ismail, Ahmad & Dahari, 2010; Kainda, Flechais & Roscoe, 2010). Two design elements associated with satisfaction are: aesthetic and user control (Lim, Song & Lee, 2012).

Table 4.6 and Figure 4.6 show the percentage level of satisfaction of usability testers after participating in the test. The ease of use and ability to successfully correct errors while using both Padlet and LibreOffice Draw had a similar level of agreement by percentage. However, during the tool rating in Table 4.7, 80% of the participants rated Padlet as 'Good' compared to 40% for LibreOffice Draw. In the post survey questionnaire, 80% of the testers preferred Padlet as a visualisation tool for learners.

Table 4.6: Satisfaction evaluation

	I found the tool easy to use		I found it easy to correct errors successfully	
	Padlet	LibreOffice Draw	Padlet	LibreOffice Draw
Strongly disagree				
Somewhat disagree	20%	20%		
Neither agree nor disagree	20%	20%	40%	40%
Agree	60%	60%	60%	40%
Strongly agree				20%

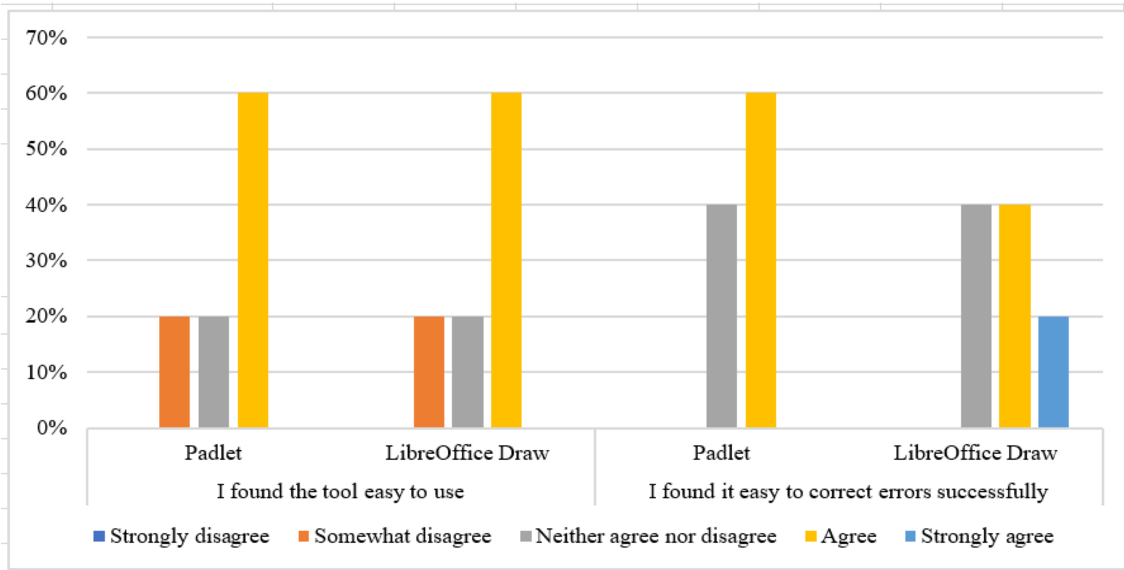


Figure 4.6: Satisfaction evaluation

Table 4.7: Tool rating

	Padlet	LibreOffice Draw
Very poor		
Average		20%
Above average	20%	40%
Good	80%	40%
Excellent		

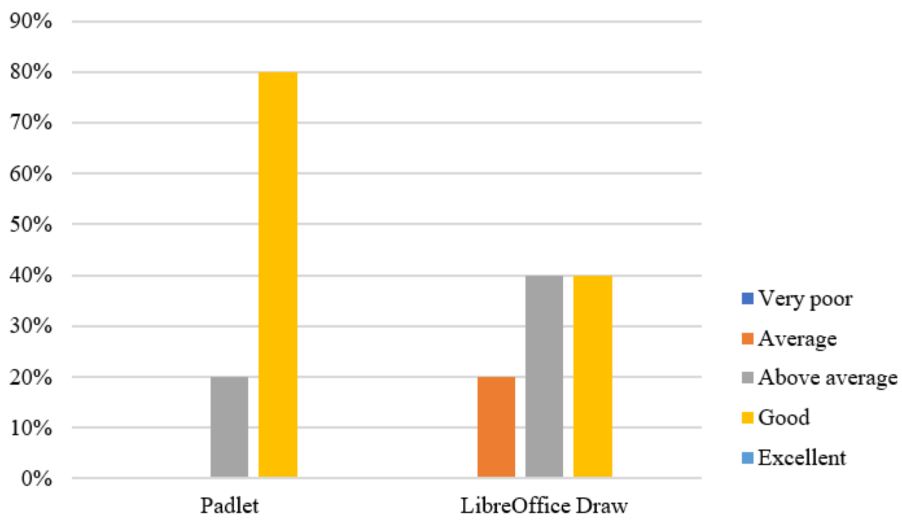


Figure 4.7: Tool rating

4.3 Post-test qualitative analysis

During the test, the researcher took note of qualitative data derived from observing the testers. In addition, post-test questionnaires, which included open-ended questions which allow for capturing new insights, were completed by the testers.

After the test, 80% of the usability testers indicated their preference for Padlet over LibreOffice Draw. The open-ended questions allowed the testers to: elaborate why they selected the tool; list additional usability functionalities that should be included in the tool but were not mentioned in the questionnaire; and justify if the use of KV had any effect on their knowledge acquisition or otherwise.

The following are some of the reasons given by testers for why they chose Padlet over LibreOffice Draw:

- Padlet presented a simpler interface.
- It is more appealing than LibreOffice Draw.
- It is easy to use.
- It is user-friendly.
- It helped in achieving goals better.

Testers that preferred LibreOffice Draw over Padlet stated that:

- It has more functionality over Padlet.
- Does not require internet access to use.

Additional functionalities in Padlet that were not stated in the questionnaire but were stated as advantages by testers included:

- Flexibility in editing images.
- Additional shapes and connectors options.
- Ease of sharing images.

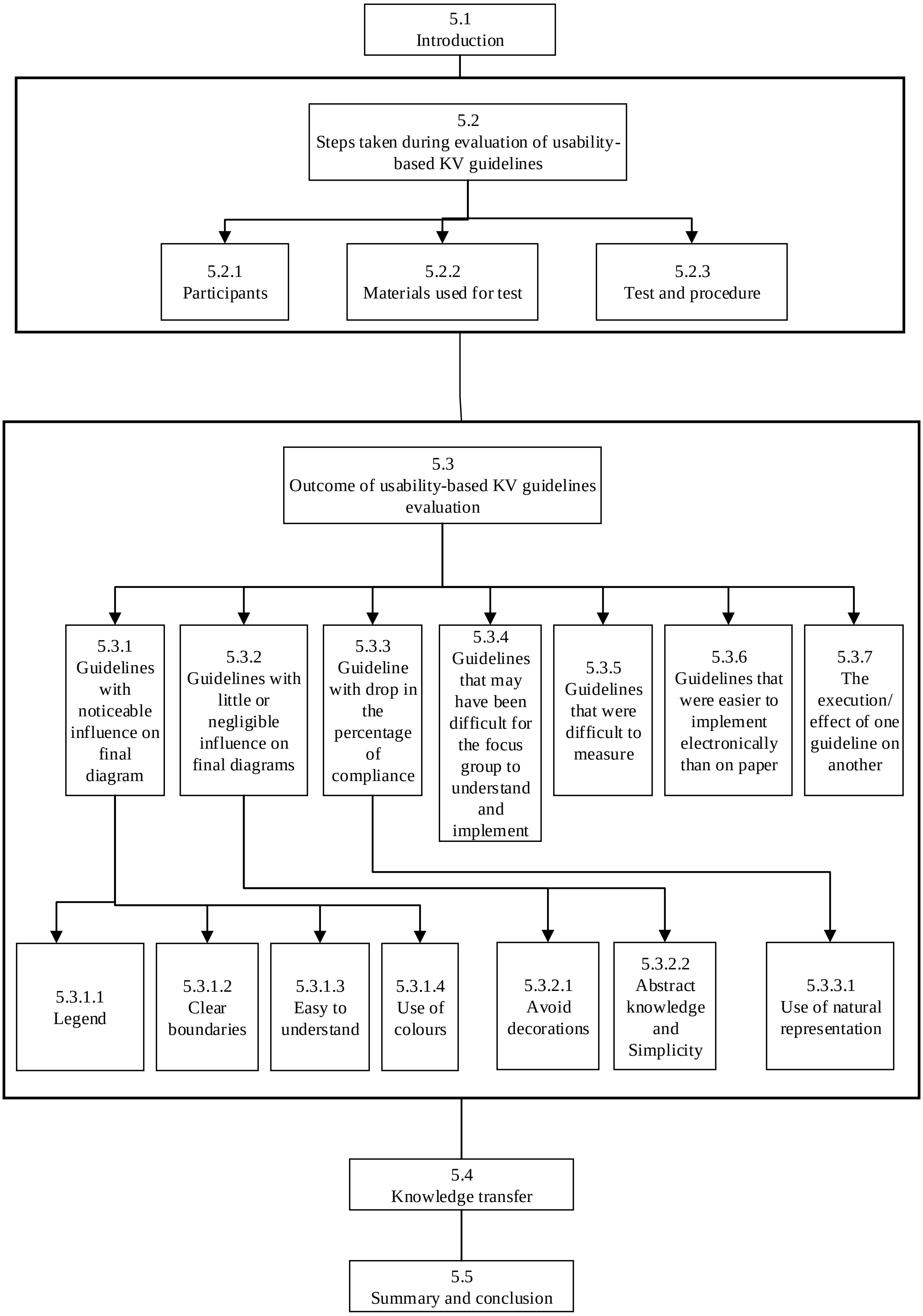
4.4 Summary and conclusion

This chapter explained the process for the selection of the appropriate KV tool used for this study. The chapter contributed to answering RQ_2 namely: "*Which usability principles are relevant to knowledge visualisation?*" and in particular $RO_{2.2}$, "*To identify usability principles relevant for the selection of visualisation tools*". The usability principles identified from literature and those relevant for the selection of KV tools are listed in Tables 3.8 and 3.9 respectively. The result of the usability evaluation, according to the usability principles relevant for the selection of visualisation tools as identified in Chapter 3, showed testers favouring Padlet as a visualisation tool over LibreOffice Draw, together with suggestions for additional functionality.

In addition, all the testers noted that KV influenced their knowledge acquisition by stating that: KV gave them more understanding; that KV made them more creative; and KV gave them freedom of expression

The next chapter discusses the process of evaluating the KV guidelines identified in Table 3.6.

Map of Chapter 5 (Evaluation of usability-based knowledge visualisation guidelines)



Chapter 5 Evaluation of usability-based knowledge visualisation guidelines

5.1 Introduction

In this chapter, an investigation into how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation is provided. It will, additionally, show how a teacher can assess the quality of knowledge that has been transferred to the learners. The evaluation of usability-based KV guidelines addresses the third research question (RQ_3), namely: *How can usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education be evaluated?* and how to achieve the third research objective (RO_3), namely: "*To investigate how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation in a way that the teacher can assess the quality of knowledge that has been transferred to learners*".

As earlier shown in Table 2.4, the design-based approach followed in this study consists of two iterative cycles of testing by the researcher. As a recap, the flowchart process for the iteration steps can be found in Figure 2.2 and the usability-based knowledge visualisation guidelines used for the procedure in section 3.6.

In section 5.2, the steps taken during the evaluation of usability-based knowledge visualisation guidelines are discussed, including: participants; materials used for the test; and test and procedures. The outcome of the evaluation is discussed in section 5.3 while the summary and conclusion of the chapter are presented in section 5.4.

5.2 Steps taken during evaluation of usability-based knowledge visualisation guidelines

For this research, the participants (high school science learners) were taught the process and stages involved in launching a rocket. They were then asked to make a diagrammatic representation of what they had learned, as a form of a test. Images produced by learners were both on paper and on a digital device. These were used for facilitating and demonstrating knowledge transfer. The procedure for the test is explained in section 5.2.3. In addition, learners were required to complete questionnaires to capture both quantitative and qualitative data. Table 5.1 below shows how learners were expected to apply each guideline identified (Table 3.6), in relation to this study.

Table 5.1 Application of usability-based knowledge visualisation guidelines

Usability-based knowledge visualisation guidelines	Expected implementation of guideline and mode of measurement
Know your data	Participants (high school science learners) were taught the processes and the stages involved in launching a rocket. Interactive discussions after the lesson to buttress their understanding of the topic were held. The guideline was measured by using the rubric for the diagram given to learners for the test i.e. suitable title (Appendix E, Part D).
Know your audience	Learners were asked to create a diagrammatic representation of the rocket launch process in the form of a presentation for their school portfolio. Some learners asked for whom the presentation was being made and were told it was for: - Fellow learners (to transfer knowledge). - Evaluating their knowledge acquisition. This guideline was not measured for this study.
Clarity	Learners were required to use text or labels to help clarify images that looked ambiguous. Using legends could also give meaning to images that might otherwise be considered unnecessary. The guideline was measured by using the rubric for the diagram.
Abstract (compress) the knowledge	Learners' diagrams were streamlined to fit what was taught and the guideline was measured by using the rubric for the diagram given to learners that is: **Labels: -** each component must be clearly outlined with aspects explained. Breakdown for marks was as follows: 1. 5 rocket launch phases clearly stated (5 marks). 2. At least 2 distinct events clearly stated in each phase (10 marks). 3. Beginning and end of the rocket launch process clearly stated (2 marks). 4. Correct sequence of rocket launch phases (4 marks).
Present overview and detail on demand	Implementing the overview and detail guideline is typically achieved by displaying two separate views simultaneously i.e. one representing the context and the other the detail (Burigat & Chittaro, 2013). Learners were not able to achieve this guideline on paper. However, some were able to achieve it electronically via the use of Padlet by uploading detailed images that could be viewed when zoomed in.
Consistency	No restriction were placed on learners while producing their first images. However, the introduction to usability-based KV guidelines enabled some learners to conform to this guideline. Learners are expected to use the same symbol for same concepts throughout. In some cases, the implementation of other guidelines affected the consistency of their final diagram. Also, consistency was easier to achieve electronically (i.e. via the use of Padlet) than on paper. This guideline was not measured for this study.
Avoid decoration	No restrictions were placed on learners on initial images produced. The guideline was measured by noting the number of learners who used images that were not consistent with the topic before and after the brief on usability-based KV guidelines.
Use natural representations	The context of the topic being visualised by the learners was such that the use of natural representation was feasible. The guideline was measured by noting the number of learners that used diagrams relating to the context of the question e.g. some learners drew rockets, fire, smoke where appropriate.
Motivate audience	This usability-based KV guideline could not be measured. It was thought to be subjective and content dependent.

Easy to understand	Compliancy to the rubric for the diagram given to learners can be considered to be sufficient to make images produced easy to understand and was used to measure adherence to the guideline i.e. - Explanatory title. - Labels: each component must be clearly outlined with each aspect explained. - Links: arrow showing the direction and relationship between two processes must be shown.
Simplicity	This guideline is subject to the type of visualisation adopted by each student participating in the reseatrch. The guideline was measured by the noting the simplicity of navigating and organisation of images produced by learners and, the absence of unnecessary complexity beyond the scope of the rubric for the diagram.
Use of colours	Learners were provided with colour pens, giving them a choice of colour-coding their work before and after briefing them on KV guidelines. On Padlet, learners have a choice of setting fun backgrounds. The guideline was measured by comparing the number of learners that made use of colours before and after the brief on the guidelines.
Dual coding	Dual coding entails using both textual and visual representation to process information. Learners were required to make a diagrammatic representation of the rocket launch process, similar to a school portfolio presentation. The guideline was not measured for this study.
Relationship between concepts clearly shown	One of the rubrics for the diagram given to learners was the use of links i.e. arrows showing the direction and relationship between two processes. The guideline was measured by learners' conformity to this rubric.
Clear boundaries	The knowledge learners were asked to visualise was such that setting clear boundaries was feasible. The guideline was measured, that is, some learners were able to visualise the phases of the rocket launch that took place on earth and in space.
Legend	Learners were required to give detailed information of the meaning of symbols used, if any, in form of a key to the images produced. The guideline was measured by learners' conformity to this instruction.

The following sections provide a detailed account of how the test was conducted and the analysis of the data obtained.

5.2.1 Participants

Eighteen high school science learners (12 males), a usability expert, a high school science teacher and the researcher took part in the evaluation of the usability-based knowledge visualisation guidelines in the form of a test. The learners were selected from various schools in Gauteng (private and public), with little or no consideration of their academic performances. This was to enable the researcher to have a fair sample of participants. All the learners had a minimum of two years' experience in the use of Information Technology devices (e.g. mobile phones, tablet, laptop, desktop computer etc.), with over 56% of the learners having over 5 years' experience. The choice to focus on only high-school science learners, as stated in section 1.5, was to initiate and develop a model which can be extended to STEM education.

Parents’ consent was obtained prior to the research test for learners under the age of 18 years, and a sample of the consent form can be found in Appendix C. The purpose of the research was explained to the parents and learners while assuring them that their children would not be endangered in any way.

5.2.2 Materials used for test

Learners were taught the processes and the stages involved in launching a rocket, they were then required to answer a test paper (Appendix E). The implementation of the research test by the learners, i.e. producing a diagrammatic representation of how rockets are launched, was carried out both on paper and with the use of an electronic device. All learners were required to produce their images both on paper and on a digital device using the Padlet visualisation tool. In addition to the test paper, each learner completed a questionnaire containing both pre-survey and post-survey questions. The results are presented in section 5.3.

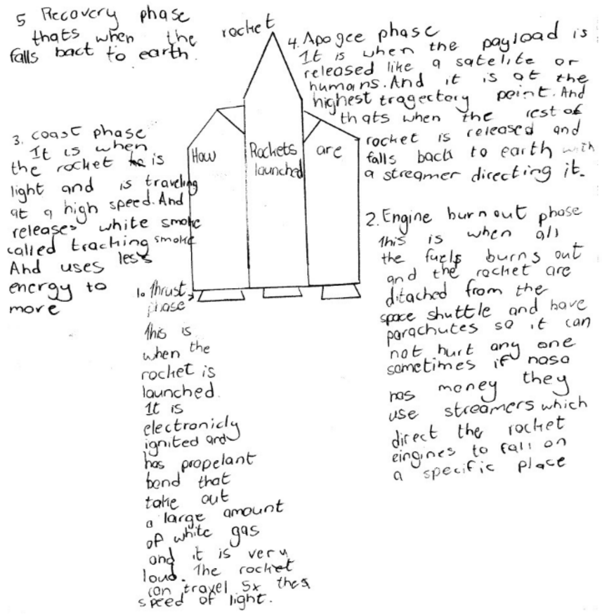
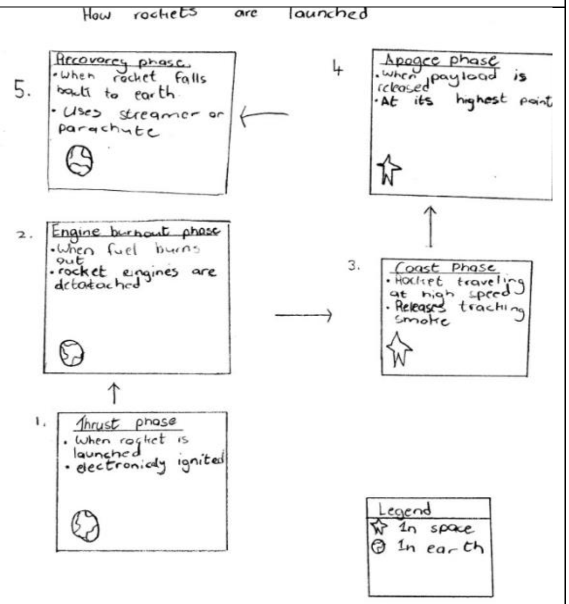
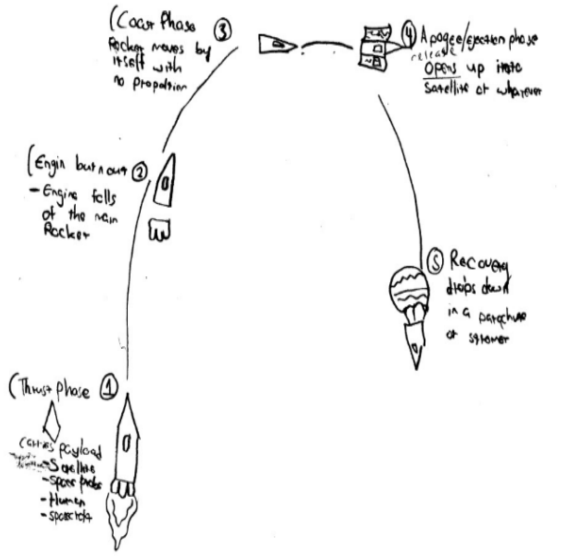
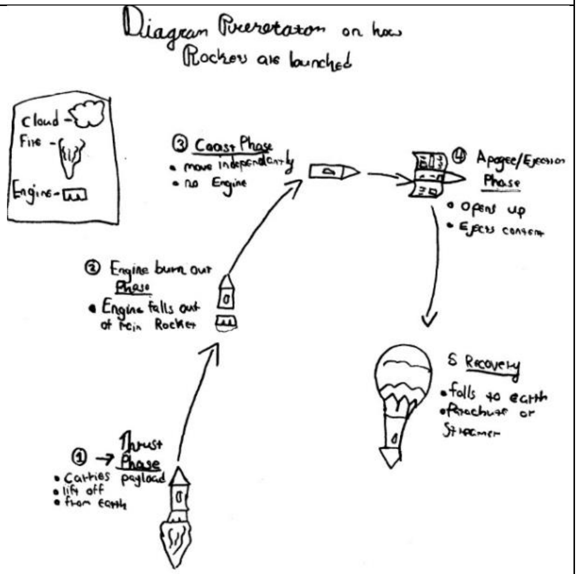
5.2.3 Test and procedure

The test took place at Rooihuiskraal library, Centurion. The room used is similar to a formal learning setting, with the provision of a digital device for each learner. The background information of each participant was captured in a pre-survey questionnaire and, after the session, a post-task questionnaire was used to capture more data.

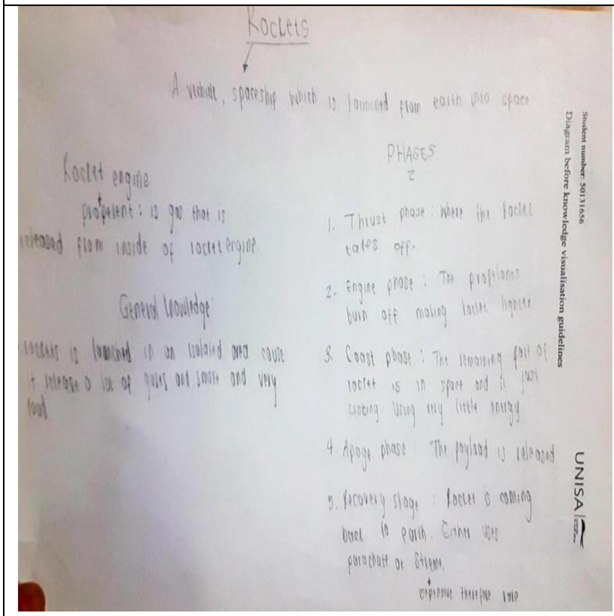
During the test procedure, learners were allowed a 30-minute break for relaxation and refreshment so as to ensure that the process was not affected by pressure and/or fatigue. As earlier stated, both qualitative and quantitative data were collected. The researcher also took notes of learners’ verbal comments while observing each learner during the session.
The steps for the procedure can be found in the iteration steps for the evaluation of usability-based knowledge visualisation guidelines flowchart in Figure 2.2.

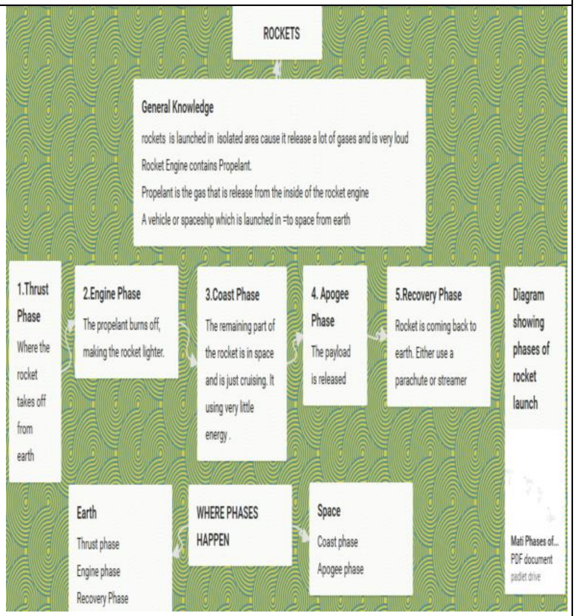
5.3 Outcome of usability-based knowledge visualisation guidelines evaluation

Figure 5.1 shows samples of learners’ diagrams before and after the brief on KV guidelines. The figure reflects some of the observations noted in subsequent sections. In Sample 1, more information is added in terms of content and structure (relations among components). In Sample 2 and 4, a title is added to the visualisation (easy to understand), together with a description of the symbols used in sample 2 (legend). Sample 3 shows the learner creating a visual image using the Padlet visualisation tool. In the new image, relationships between concepts are clearly shown. The sample 1 learner considered a visualisation to be a central picture and the guidelines led to fragmentation. Obviously, that would not be at the expense of coherence, so the unintended consequences of the guidelines needed to be monitored throughout.

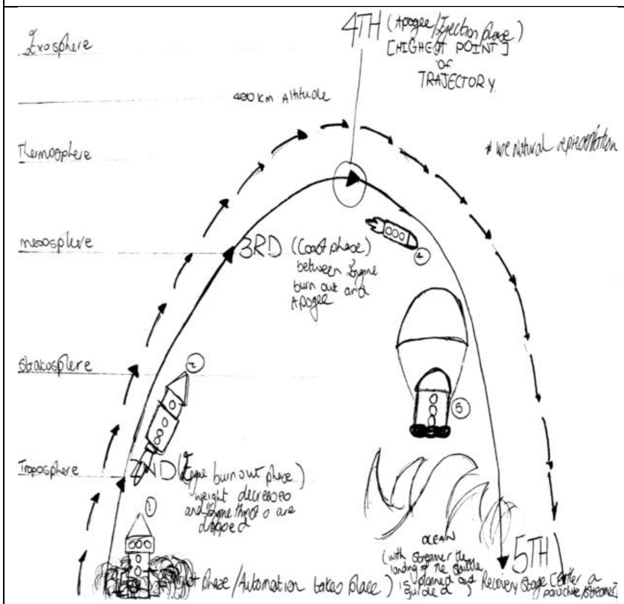
<table>
<tr><th>Before</th><th>After</th></tr>
<tr><td colspan="2">Sample 1</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Sample 2</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Sample 3





Sample 4



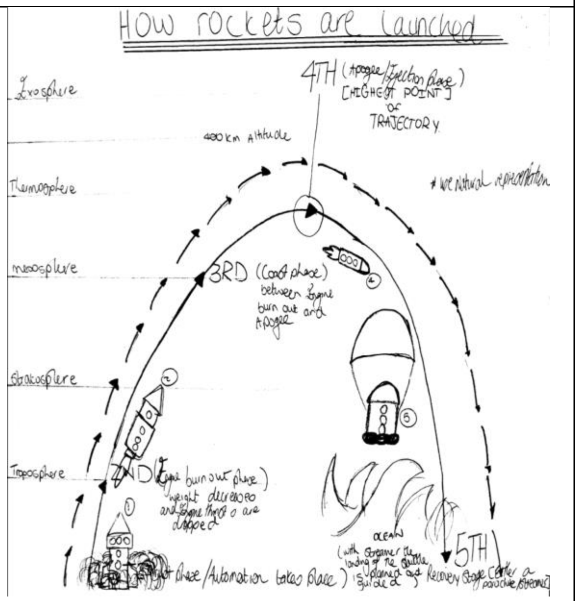


Figure 5.1 Samples of learners' visualisation before and after usability-based knowledge visualisation guidelines brief

Table 5.2 and Figure 5.2 show the conformity of learners to usability-based knowledge visualisation guidelines, before and after briefing them on the principles in a tabular and graphical format. Figure 5.2 shows the percentage change in learners' compliance to usability-based knowledge visualisation guidelines after being briefed on what KV entails. Table 5.2 gives the percentage levels of compliance as a numerical value of each usability-based knowledge visualisation guideline. The interpretation of the results is discussed in subsequent sections.

Table 5.2: Percentage level of compliancy by learners before and after the brief on usability-based knowledge visualisation guidelines

	Know your data		Abstract knowledge		Clarity		Avoid decoration		Use of natural representation		Easy to understand		Simplicity		Use of colours		Clear boundaries		Legend		Relationship between concepts shown	
	Before	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**	**Before**	**After**
Yes	22%	94%	72%	89%	78%	100%	89%	94%	61%	56%	17%	94%	89%	100%	11%	39%	11%	44%	0%	44%	61%	94%
No	78%	6%	28%	11%	22%	0%	11%	6%	39%	44%	83%	6%	11%	0%	89%	61%	89%	56%	100%	56%	39%	6%
% increase in compliance	72%		17%		22%		5%		-5%		77%		11%		28%		33%		44%		33%	

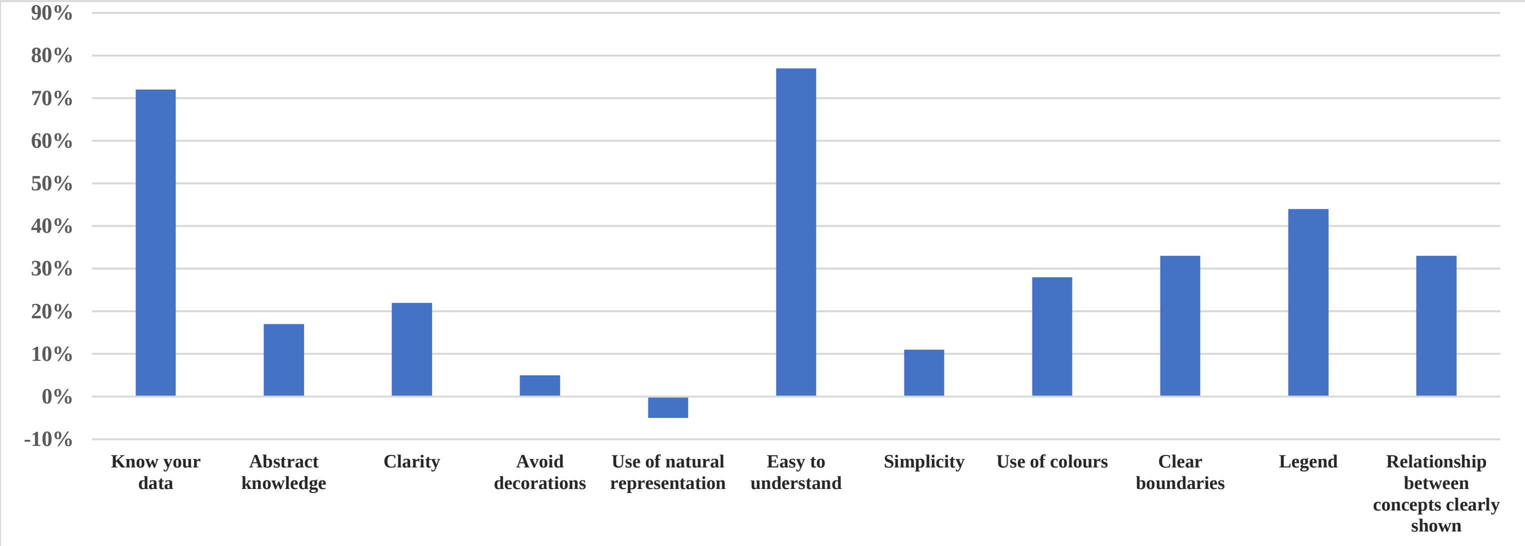


Figure 5.2: Graph showing percentage increase/decrease in compliance

5.3.1 Guidelines with noticeable influence on final diagram

From Table 5.2 and Figure 5.2 above, the following guidelines had a noticeable influence on the final diagram ranging in percentage from a 22% to 77% compliancy level: Legend, Clear boundaries, Easy to understand, Use of colours, Know your data, Clarity and Relationship between concepts clearly shown. Each of these guidelines are discussed below:

5.3.1.1 Legend

A legend is an accompanying item to a visualisation which: provides detailed explanations on symbols used, can become a control panel for making changes e.g. colour palettes, marker attributes etc., and also provide multiple views of data (Heer, Shneiderman & Park, 2012; Hall & Virrantaus, 2016). None of the learners added a legend in their initial visualisation. However, after the brief on usability-based knowledge visualisation guidelines, 44% of the learners felt there was a need to give a meaningful explanation of the symbols used by adding a legend, thereby aiding other usability-based knowledge visualisation guidelines.

Figure 5.3 below is an example of a learner who added a legend to the initial visualisation produced.

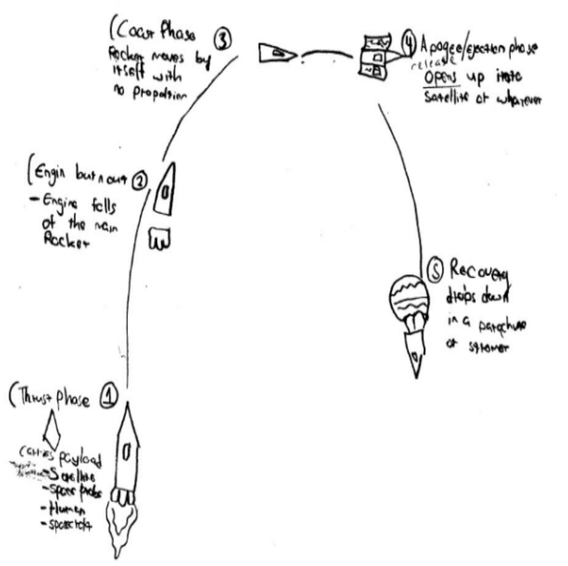
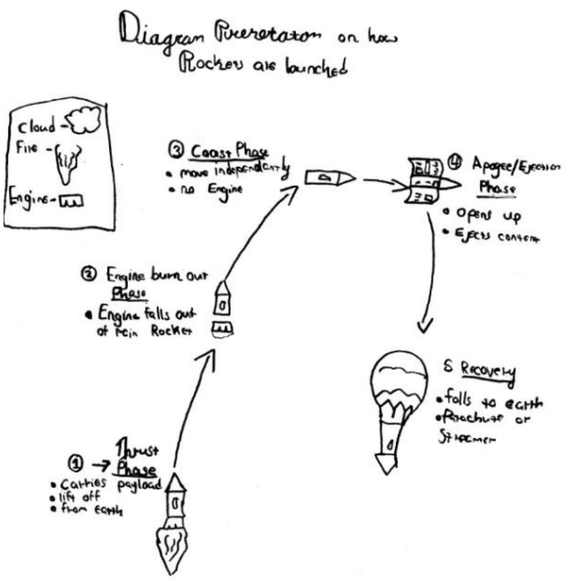
Before usability-based knowledge visualisation guidelines brief	**After usability-based knowledge visualisation guidelines brief**
	

Figure 5.3: Sample of learner adding 'Legend' to visualisation

5.3.1.2 Clear boundaries

Diakopoulos, Kivran-Swaine and Naaman (2011) explain that setting clear boundaries while visualising can help with navigation as geographic trends can be noted across regions. Boundaries can also be used for enclosing knowledge within a specific domain (Keller, 2005). However, clear boundaries may be subject to the context of the topic being visualised, that is the guideline is less applicable when the visualisation is within the same domain. The image being visualised is the process of a rocket launch. Some learners were able to specify the location of each phase of the rocket launch before the KV brief while some only added clear boundaries after the KV brief (see Figure 5.4 below).

5.3.1.3 Easy to understand

The high level of compliance with the 'Easy to understand' guideline was influenced by the compliancy to other guidelines such as: Abstract knowledge; Clarity; Use of natural representation; Legend; Relationship between concepts clearly shown; simplicity; and clear boundaries, indicating inter-guideline dependencies. Bresciani and Eppler (2009) argue that when a diagram is easy to understand, little previous knowledge will be required.

5.3.1.4 Use of colours

Although there was a percentage increase of 28% due to the use of colours after the brief on KV guidelines, a number of learners were cautious about the way they implemented this principle to avoid compromising other principles such as 'avoid decorations'. For others, it was a quick way to implement the 'clear boundaries' principle as shown in Figure 5.4 below.

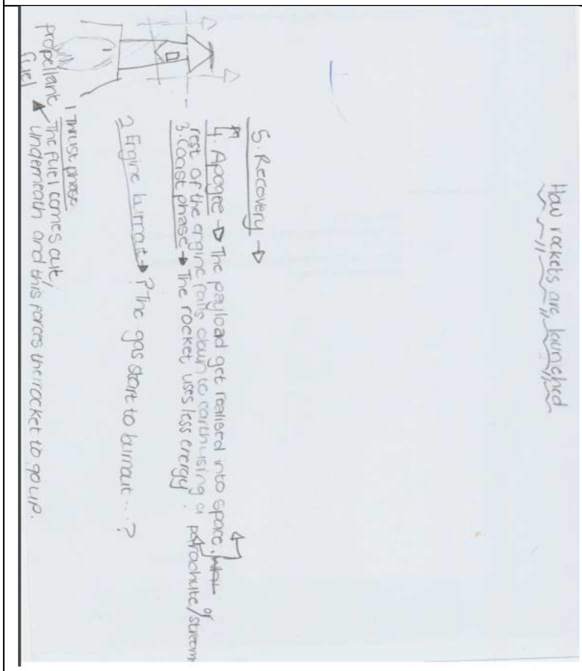
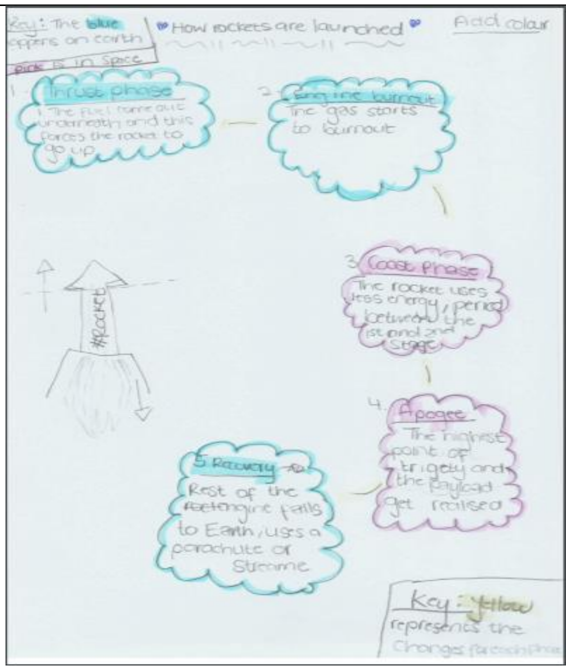
Before usability-based knowledge visualisation guidelines brief	After usability-based knowledge visualisation guidelines brief
	

Figure 5.4: Sample of learner applying the ‘Use of colours’ guideline to implement ‘Clear boundaries’

5.3.2 Guidelines with little or negligible influence on final diagrams

The guidelines: ‘Abstract knowledge’, ‘Avoid decorations’ and ‘Simplicity’ had compliancy levels ranging from 5% to 17%. The rubric for the question may have contributed to learners’ compliancy before the brief, thus making the guidelines have little or negligible influence on the final diagram produced. In addition, the test was timed, and it was observed that learners were focusing more on abstract information that would yield more marks for them.

5.3.2.1 Avoid decorations

From observation, 89% of the learners originally created a visualisation, void of symbols, and whose meaning was not related to the content of the study. Thus, the ‘avoid decorations’ principle did not make a substantial difference in the final images produced by the learners, especially after a legend was added to give meaning to symbols used. Figure 5.5 below shows a learner taking out the image of a rocket used in the initial visualisation to conform to the ‘Avoid decoration’ guideline.

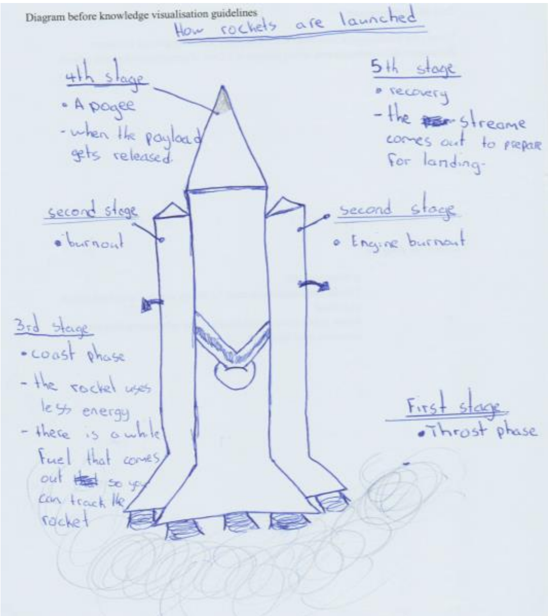
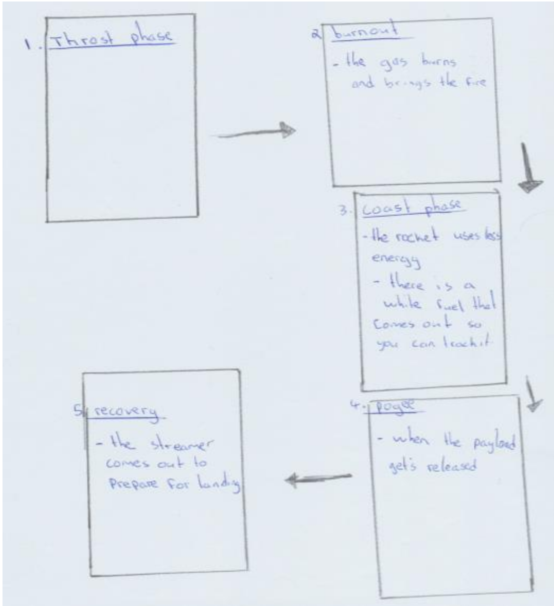
Before usability-based knowledge visualisation guidelines brief	**After usability-based knowledge visualisation guidelines brief**
	

Figure 5.5: Sample of learner adhering to 'Avoid decoration' guideline

5.3.2.2 Abstract knowledge and Simplicity

The 'Abstract knowledge' and 'Simplicity' principles had minimal impact on the final images produced by learners, with a percentage conformity level 17% and 11% respectively. For 'Abstract knowledge', this may have been because of time constraint, thus making learners include only the most important points before the allotted time elapsed. The nature of the topic being visualized may account for the 'Simplicity' guideline not having an effect.

5.3.3 Guideline with a drop in the percentage of compliance (Use of natural representation)

Learners in the research group did have personal preferences when using visualisation to represent knowledge. While most agreed that using images to represent and transfer knowledge is a field they were willing to explore, others expressed their reservations. The latter believed that to implement KV necessitated being artistically inclined.

5.3.3.1 Use of natural representation

In view of these, there was a 5% drop in the compliance level for participants who expressed their concern about their representation of the real world possibly violating another principle, that is 'Avoid decorations.' Furthermore, it is argued that the use of natural representation can be subject to the designer's background. For example, the use of fire to represent a volcanic eruption in the geographical field may be seen as heat in the chemical field.

5.3.4 Guidelines that may have been difficult for the participants to understand and implement

Learners found the 'Motivate audience' guideline difficult to implement. Some of the questions raised were: whether to make the images produced very attractive, add a motivational paragraph in form of an introduction to the diagram, or produce images that speak to a particular audience. Ultimately, the learners argued that implementing these suggestions could compromise some of the other principles such as abstracting the data and avoiding decorations.

5.3.5 Guidelines that were difficult to measure

The guidelines: 'Know your audience'; 'Motivate audience'; and 'Dual coding' were explained to the learners, but the visualisation was not evaluated for those guidelines. This is because the guidelines were subjective and content dependent, and therefore, difficult to measure for this target group. Likewise, the guideline 'Consistency' was difficult to measure in the context of a diagram produced by learners and was either edited or redrawn to accommodate the usability-based KV guidelines.

5.3.6 Guidelines that were easier to implement electronically than on paper

Most learners found it easier to implement the electronic execution of the 'Present overview and detail' principle than doing it on paper. Accounting for this preference could be that devices used for visualisation, e.g. desktop computers, laptops etc. usually have inbuilt technologies that makes it possible to zoom in on a particular section of an image, a feature that would not be applicable on paper. However, it is important to note the issue of usability in e-learning where there is the need to first know how to use the application (Ssemugabi & De Villiers, 2010).

5.3.7 The execution/effect of one guideline on another

Implementing some guidelines increased the level of conformity of others. In essence, some guidelines were observed to be inter-related as the application of one gave credence to the implementation of another. Examples are:

- Legend (Clarity, Easy to understand, Consistency).
- Easy to understand (Simplicity, Abstract the data, Avoid decorations).
- Avoid decoration (Legend).

- Use of colours (Clear boundaries).

5.4 Knowledge transfer

The term ‘knowledge transfer’ according to (Wang & Noe, 2010:117) “involves both the sharing of knowledge by the knowledge source and the acquisition and application of knowledge by the recipient’’. Knowledge transfer can be defined as the transmission of knowledge from one place, person or ownership to another (Liyanage, Elhag, Ballal & Li, 2009).

According to Zhong and Zhang (2009), teachers can convey information together with knowledge to learners during the process of teaching and learning. However, personalising the information by learners requires the ability to rebuild the knowledge. They further explained that KV is an approach to complete the process of rebuilding knowledge. In addition, KV can be used by teachers to transfer easily understandable visual metaphors as the brain can more easily process images than it can with text (Eppler & Burkhard, 2007).

An effective knowledge transfer from teachers to learners determines learners’ performance and satisfaction (Ahmad, Ahmad & Rejab, 2011). The researcher observed that there was an increase in the average marks of learners from 52% to 56% after the brief on usability-based knowledge visualisation guidelines as shown in Table 5.3 and Figure 5.6. The minimum percentage difference was 0% for learners who did not feel a need to modify their images and a maximum of 12% for a learner who was able to take advantage of the usability-based knowledge visualisation guidelines to modify the initial image produced. This is evidence of knowledge transfer between the teacher and learners during this study.

Table 5.3: Learners' marks before and after brief on usability-based knowledge visualisation guidelines

Participant	Marks before brief	Marks after brief
1	53%	57%
2	50%	53%
3	44%	54%
4	58%	62%
5	62%	65%
6	53%	55%
7	39%	44%
8	54%	58%
9	57%	64%

10	50%	57%
11	49%	51%
12	40%	43%
13	58%	58%
14	55%	63%
15	52%	52%
16	55%	55%
17	58%	58%
18	55%	67%
Average	52%	56%

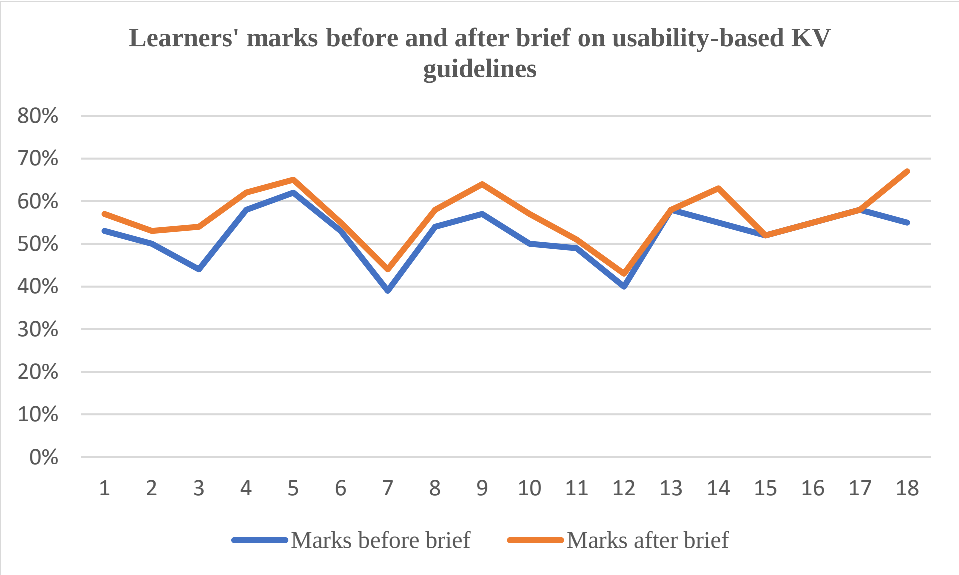


Figure 5.6: Learners' marks before and after brief on usability-based knowledge visualisation guidelines

Table 5.4 shows how the usability-based knowledge visualisation guidelines were prioritised based on the percentage increase or decrease in conformity by learners. It will be observed that the 'Easy to understand' guideline is ranked the highest with a 77% degree of conformity while 'Use of natural representation' has the lowest, with a drop in degree of conformity to -5%.

Table 5.4: Prioritisation of usability-based knowledge visualisation guidelines

Position	**Usability-based knowledge visualisation guidelines**	**Degree of conformity**
1	Easy to understand	77%
2	Know your data	72%
3	Legend	44%
4	Clear boundaries	33%
5	Relationship between concepts clearly shown	33%

6	Use of colours	28%
7	Clarity	22%
8	Abstract knowledge	17%
9	Simplicity	11%
10	Avoid decorations	5%
11	Use of natural representation	-5%

Table 5.5 shows the post survey reaction of learners to the use of KV in teaching and learning. Sixty one percent of the learners agreed that the use of usability-based knowledge visualisation guidelines influenced their final diagram while 83% said they will consider using the usability-based knowledge visualisation guidelines as a means of exhibiting knowledge transfer to others. In addition, 94% of the learners think the use of KV had an effect on their knowledge acquisition.

Some of the justifications stated by learners are stated below:

- Effect of knowledge visualisation guidelines on diagram includes: Images produced is clearer and simpler, helps in abstraction, improved image quality.
- Effect of KV on knowledge acquisition includes: Ease of studying, new knowledge is learnt, ease of understanding of new topics, promotes memorability, promotes simplification in learning, clarity.

Table 5.5: Post survey reaction of learners to the use of knowledge visualisation

Response	Did the use of knowledge visualisation guidelines had any effect on your final diagram?	Will you consider using the knowledge visualisation guidelines as a means of exhibiting knowledge transfer to others?	Do you think the use of KV had any effect on your knowledge acquisition?
Yes	61%	83%	94%
No	39%	17%	6%

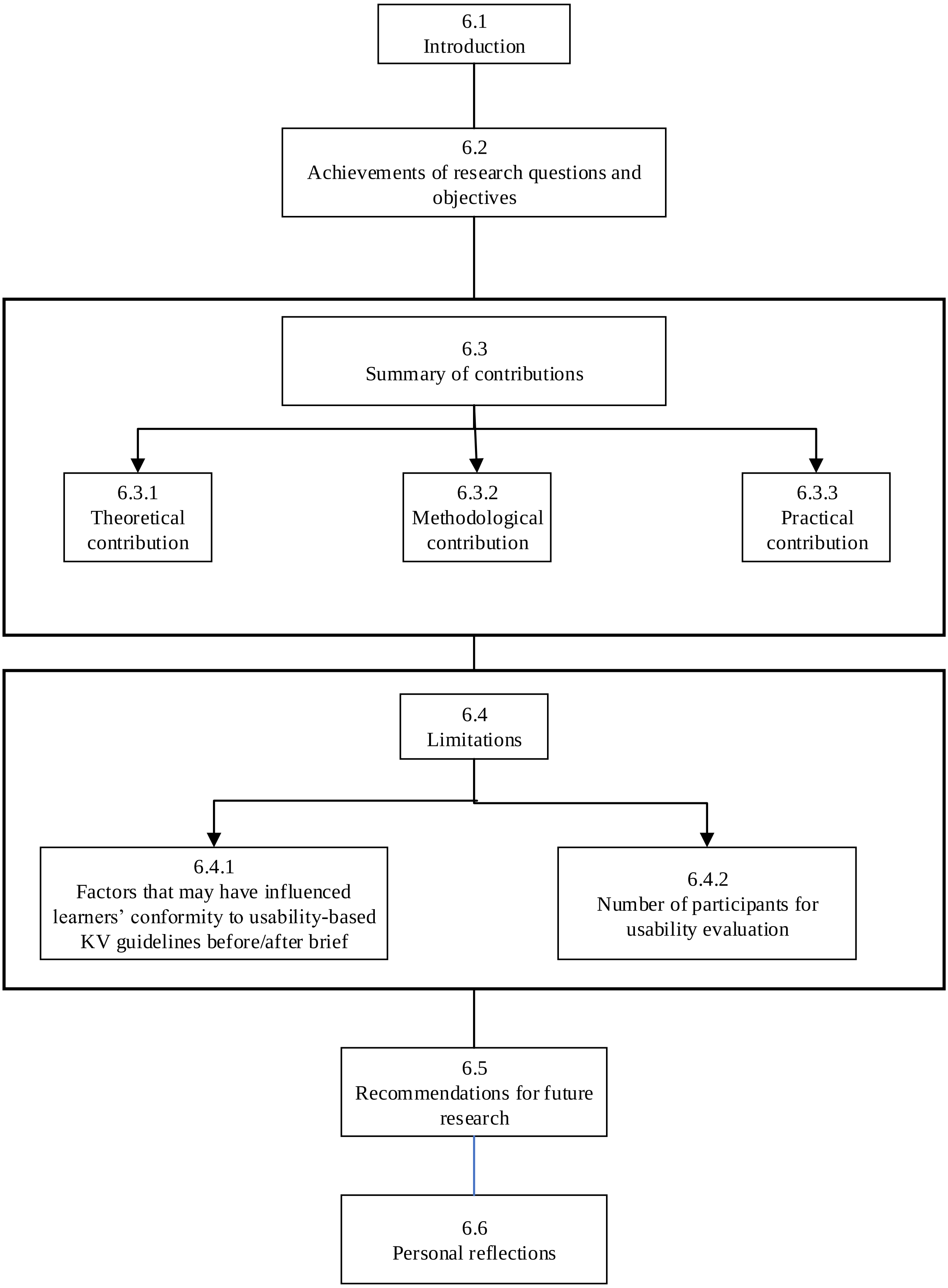
5.5 Summary and conclusion

The findings indicate that most of the principles considered in this study had various degrees of impact on the images produced by learners. While for some, the impact was significant, for others it could be considered negligible. This calls for prioritisation of the usability-based knowledge visualisation guidelines, with the context of high school science learners being a consideration.

Knowledge acquisition is the process of obtaining new information, and the success of acquiring knowledge can be measured by how well the information can be remembered (Parra-Requena, Molina-Morales & García-Villaverde, 2010). In Table 5.2, the degree of learners' conformity to the presentation of usability-based knowledge visualisation guidelines is shown. Based on the results in Table 5.3 and Figure 5.6, it can be argued that the use of KV improved knowledge acquisition. In this chapter, the third research question (RQ_3), that is: '*How can usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education be evaluated?*' is answered.

The next chapter concludes this dissertation, lays out all the findings and the contributions of this study, followed by recommendations for future research.

Map of Chapter 6 (Conclusion)



Chapter 6 Conclusion

6.1 Introduction

The aim of this study was to develop usability-based knowledge visualisation guidelines for learners in order to support knowledge acquisition and transfer in such a way that teachers can assess the quality of knowledge that has been transferred to learners. To achieve this, the researcher analysed the effect of usability-based knowledge visualisation guidelines on the visual representations learners produced during an intervention. The analysis was done on visualisations created both before and after they were briefed on the guidelines. This yielded the prioritisation of the usability-based knowledge visualisation guidelines, based on the conformity of images produced by learners to the guidelines. According to Wright (2012, p.1), "powerful learning begins to manifest when students take responsibility and ownership for their learning when they become co-creators of their learning experience, rather than their education being something that is done to them. True student empowerment and engagement begins when we cross the threshold of co-creation". This, therefore, provides an opportunity for learners to switch from being passive participants to becoming active participants in creating knowledge for themselves by using knowledge visualisation principles to improve knowledge transfer to others.

In section 6.2, the research findings are discussed based on the research questions and objectives for this study. In section 6.3, a summary of the contribution of this study is presented. Limitations and suggestions for further research are discussed in sections 6.4 and 6.5 respectively, while personal reflections are offered in section 6.6.

6.2 Achievements of research questions and objectives

The research questions and the processes followed to answer them are briefly described below, together with the sections where the findings are discussed in detail. The main research question for this study, posed in section 1.3.2 is: 'How can usability principles inform knowledge visualisation guidelines to support knowledge transfer in high-school science education?'

To answer this question, the following sub-questions were posed:

RQ$_1$: What are the existing knowledge visualisation principles for teaching and learning?

KV principles relating to teaching and learning were extracted from literature using a SLR. These principles can be found in Table 3.6 and the process of answering the question can be found in section 3.6.

RQ_2: Which usability principles are relevant to knowledge visualisation?

To answer this question, HCI usability principles relevant to visualisation were extracted from literature (Table 3.8), and the usability principles relevant for selecting a relevant visualisation tool for teaching and learning were identified (Table 3.9). These principles can be found in section 3.7.3 and the process of answering the question can be found in Chapter 4.

RQ_3: How can usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education be evaluated?

RQ_3 directed the investigation on how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation in a way that the teacher can assess the quality of knowledge that has been transferred to the learners. To answer this question, usability-based knowledge visualisation guidelines were extracted from literature (section 3.6) and evaluated (Chapter 5). The process of evaluation involved the learners creating a diagrammatic representation of how rockets are launched. The first images created were analysed based on their conformity to usability-based knowledge visualisation guidelines. Learners were then introduced to these guidelines and asked to recreate or modify the images produced so as to conform to these usability-based knowledge visualisation guidelines. Analysis was done on the second image and comparison was done on the level of conformity to usability-based knowledge visualisation guidelines on the two images produced by each learner. The process was part of the first and second phase in the design-research phase, that means the guidelines were developed by the researcher and then evaluated according to the way learners implemented them. This allowed prioritisation of the usability-based knowledge visualisation guidelines.

The guidelines used, together with reasons or explanations for their recommendation can be found in Table 3.6. and the process of answering the question can be found in Chapter 5. Prioritised usability-based knowledge visualisation guidelines are presented in Table 5.4.

6.3 Summary of contributions

The assessment stage is the final phase of the DBR and it includes assessing the theoretical, methodological and practical contribution. Table 6.1 below shows the contribution of each research question in relation to this study.

Table 6.1: Table showing achievement of research questions and type of contribution

Research Questions	Research objectives	Output	Type of contribution
RQ$_1$: What are the existing knowledge visualisation principles for teaching and learning?	**RO**$_1$**:** To identify knowledge visualisation principles applicable to teaching and learning from literature	Table 3.6	Theoretical
RQ$_2$**:** Which usability principles are relevant to knowledge visualisation?	**RO**$_{2.1}$**:** To identify usability principles relevant to knowledge visualisation	Table 3.8	Theoretical
	RO$_{2.2}$**:** To identify usability principles relevant for the selection of visualisation tools	Table 3.9	
RQ3: How can usability-based knowledge visualisation guidelines for knowledge transfer in high-school science education be evaluated?	**RO**$_3$**:** To investigate how usability-based knowledge visualisation guidelines can be used by learners to aid knowledge internalisation in a way that the teacher can assess the quality of knowledge that has been transferred to learners	Table 5.2 Figure 5.2	Methodological and practical

6.3.1 Theoretical contribution

The findings from the literature analysis contributed to: the researcher's understanding of the use of KV for teaching and learning; identifying the prominent limitations of KV; and having made an informed choice regarding the appropriate methodology for the study. These findings from literature (Table 3.2) indicate that:

- There are more studies on the use of knowledge visualisation in learning than in teaching.
- The prominent design methodology in KV is that of DBR.
- A common limitation of KV is that it is domain specific and, thus, difficult to generalise. In addition, there is the risk of possible distortion of reality through misinterpretations.
- Future research noted includes but is not limited to: application of visualisation methods in learning; extending findings to new domains; enhancing the features of visualisation tools; further exploration on the use of KV to reduce cognitive load and improve the self-regulated learning process; and actively engaging learners in creating KV.

The characteristics of DBR, as stated in Table 2.3, made it the design methodology of choice for this study. The study was conducted with science learners but there is need to extend the evaluation of the usability-based knowledge visualisation guidelines to other domains so as to have a wider sample for the prioritisation of the guidelines. In addition, the findings from the study show that the use of KV and other ICT components in teaching and learning can be beneficial since, as shown in Table 5.3 and Figure 5.6, there was an improvement in learners' average marks. From the table, it will be noted that the learners' average mark increased from 52% (before the brief on usability-based knowledge visualisation guidelines) to 56% (after the brief). This correlates with findings from literature indicating that KV can be used to: improve learning abilities; improve communication and interaction around cognitive processes; and improve learners' attitude towards learning (Bertschi et al., 2011; Wang et al., 2011; Van Biljon & Renaud, 2015a; Sun, Li & Zhu, 2016).

The theoretical contributions of this study include the following:

- *Identifying HCI usability principles relevant for the selection of knowledge visualisation tools:* The HCI usability principles selected are: Learnability, Flexibility, Consistency, Effectiveness, Efficiency and Satisfaction (see Table 3.9 in Section 3.7.3). These principles were extracted from literature and used in usability evaluation to select the most appropriate KV tool for this study. The process for the tool selection is discussed in Chapter 4 and the preferred tool was Padlet.
- *Identifying knowledge visualisation principles applicable to teaching and learning:* The principles was extracted from literature and are discussed in Table 3.6.
- *Intersecting HCI usability principles and knowledge visualisation guidelines to create usability-based knowledge visualisation guidelines*: The usability-based knowledge visualisation guidelines developed and applied in this study can be found in Table 3.7 and include Abstract (or compress) the knowledge, Easy to understand, Know your data, Clarity, Use natural representations, Legend, Use of colours, Avoid decorations, Relationship between concepts clearly shown, Simplicity, and Clear boundaries. These guidelines are supported by reasons and explanations from literature and validated by the researcher. The findings indicate that most of the guidelines considered in this study had an impact on the images produced by learners. While some had a significant impact, for others it could be considered negligible. This justifies the prioritisation of usability-based knowledge visualisation guidelines, with the context for this being high school science learners in Table 5.4.

6.3.2 Methodological contribution

The main methodological contribution of this study has been the combination and application of concepts from Human Computer Interaction and information visualisation to study the process of adoption and use of usability-based knowledge visualisation guidelines in teaching and learning. The process consists of a novel combination of HCI usability principles to inform KV. Implementing the research indicated that usability-based knowledge visualisation guidelines can be utilised for knowledge acquisition and transfer.

Another methodological contribution lies in the experience gained through the application of the design-based approach and techniques applied for both quantitative and qualitative data collection. The procedure could inform further research on the use of usability-based knowledge visualisation guidelines in other fields.

6.3.3 Practical contribution

The practical contributions made by this study consist of the selection of a suitable knowledge visualisation tool and the prioritisation of usability-based knowledge visualisation guidelines. Knowledge contribution, e.g. the study of knowledge transfer between individuals is not new (Hevner & Gregor, 2013). However, this study proposes a novel contribution to how knowledge can be acquired and transferred. Table 5.3 and Figure 5.6 show the test scores of learners before and after the introduction of usability-based knowledge visualisation guidelines. It can be observed that the introduction of the guidelines improved the pass rate or class average from 52% to 56% and that the post-survey questionnaires filled in by learners show that most of the learners believe they benefitted from exploring the use of usability-based knowledge visualisation guidelines in modifying their images. In addition, the results of the qualitative investigation (Table 6.2) show that teachers and learners are positively open to an increase in the use of digital devices for teaching and learning.

6.4 Limitations

The following sub-sections discuss the limitations encountered during this study.

6.4.1 Factors that may have influenced learners’ conformity to usability-based knowledge visualisation guidelines before/after brief

Various factors may have influenced learners’ compliance with usability-based knowledge visualisation either before or after the brief. These include aspects such as providing a rubric for the diagram, information overload, and the time constraint.

Knowledge-based visualisation applications work only on specific domains/tasks and thus cannot be generalized (Eppler & Burkhard, 2004; Wang et al., 2011; Scarpato, Maria & Pazienza, 2012; Evert, 2015; Sun, Li & Zhu, 2016).

There is also the risk of possible distortion of reality through misinterpretations (Eppler & Burkhard, 2004).

The diversity in learners literacy skills and learning styles may also affect how knowledge visualisation can be used for teaching and learning (Lin & Chen, 2008). In addition, broader contexts such as language barriers, culture, beliefs, ideology (Gabriella, Marco & Alessio, 2017) might have impacted on the outcome of the research. Learners from schools with limited infrastructures and minimal availability of modern technology may be at a disadvantage, when compared with learners from first world countries.

The lack of automatization in the process of creating KV (Scarpato, Maria & Pazienza, 2012) and the constraints of the mobile technology platform on which KV can be implemented e.g. connectivity, power, size of screen, memory etc. (Van Biljon & Renaud, 2015c) may have played a role.

There is a high tendency to provide too much information to learners during teaching and learning which may also have led to disorientation and cognitive overload (Aidi, 2009).

Furthermore, participants' different learning, verbal, cultural or hierarchical styles may have affected feedback (Bastien, 2010).

6.4.2 Number of participants for usability evaluation

During a usability test, it is important that the number of test participants used allow for a complete evaluation of the application being assessed while avoiding redundant testers (Bastien, 2010). There has been no universally acceptable number of usability testers that is required for any particular usability evaluation as some researchers have proven that an average of four to five testers can uncover about 80 to 85% of usability problems, while others argue that more participants are needed to increase the chances of uncovering more usability flaws (Bastien, 2010; Albert & Tullis, 2013; Fox, 2015). For this study, five participants were involved in the usability evaluation and this may have had an impact on the selection of the visualisation tool used for this study.

6.5 Recommendations for further research

This study was conducted with science learners from various high schools in the urban area of Pretoria, South Africa. There is need to extend the research to rural areas and other provinces as participating learners could have had undue advantage because digital devices are available at their schools. This may have had an impact on their ease of adaptation to the technology used.

Furthermore, there is a need to replicate this research with larger numbers of participants and also to extend the evaluation of the usability-based knowledge visualisation guidelines within STEM teaching and learning in order to generalise the findings. Considering other domains such as arts, social sciences, humanities, applied sciences etc. will provide a wider sample for the generalisation and possible adaptation of the guidelines.

The Padlet visualisation tool can be updated in order to enhance its current features. According to reflections from the post-survey of usability testers, further research and enhancement of features could include: import and more intuitive templates for pictures, more options for image editing, and increase in user flexibility.

A final observation accentuated by this research is the readiness of educators to embrace the use of KV in teaching and learning on the condition that there are usable guidelines for optimum implementation.

6.6 Personal reflections

The multi-year process of conducting this research study was unlike any previous educational experience. At every step I endeavoured to keep an open mind and had no preconceived ideas about what the eventual findings would be. As other researchers have discovered, the outcomes of a study may not necessarily provide the expected results. It became very clear that the context within which a study is conducted is pivotal to the findings and conclusions.

Another notable lesson learned while analysing my data was the logic and depth of reasoning required of me in order to reach the conclusions that became the basis of my research. Using triangulation of the data accentuated some of the results that may have otherwise looked far-fetched.

I embarked on this research journey not knowing how open teachers and learners would be to break from the conventional methods of knowledge transfer and acquisition. I soon found that the desire for success and the extent to which innovation and technology have been embraced were key motivators for agreeing to participate in my study.

One conclusion that stands out for me after experiencing this research journey is that the current and future generation of learners are not going to be bound to the principles and guidelines that have previously dictated how we live our lives in the present. The learners and educators of tomorrow are more pragmatic and solution-oriented in their approach to education and there is a need to accommodate these trends when designing for knowledge transfer.

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Appendix A Ethical clearance

UNISA university of south africa

UNISA COLLEGE OF SCIENCE, ENGINEERING AND TECHNOLOGY'S (CSET) RESEARCH AND ETHICS COMMITTEE

20 April 2017

Ref #: 023/OAF/2017/CSET_SOC
Name: Olakumbi Anthonia Fadiran
Student #: 50131656

Dear Olakumbi Anthonia Fadiran

Decision: Ethics Approval for three years (Humans involved)

Researcher: Olakumbi Anthonia Fadiran
P.O BOX 5579, The Reeds
olakumbi@gmail.com, telephone +27 76 351 2359

RECEIVED
2017 -04- 26
OFFICE OF THE EXECUTIVE DEAN
College of Science, Engineering and Technology

Supervisor (s): Prof Van Biljon
vbiljja@unisa.ac.za, +27 11 670-9182
Dr Schoeman
schoema@unisa.ac.za, +27 11 670-9178

Proposal: Using knowledge visualialisation to demonstrate learners' knowledge acquisition

Qualification: MsC in Computing

Thank you for the application for research ethics clearance by the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee for the above mentioned research. Ethics approval is granted for a period of three years from 20 April 2017 to 20 April 2020.

1. The researcher will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should

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be communicated in writing to the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.

3. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.
4. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.

Note:

The reference number 023/OAF/2017/CSET_SOC should be clearly indicated on all forms of communication with the intended research participants, as well as with the Unisa College of Science, Engineering and Technology's (CSET) Research and Ethics Committee

Yours sincerely

Adele da Veiga

Dr. A Da Veiga

Chair: Ethics Sub-Committee School of Computing, CSET

Prof I. Osunmakinde

Director: School of Computing, CSET

Prof B. Mamba

Executive Dean: College of Science, Engineering and Technology (CSET)

Approved - decision template – updated Aug 2016

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
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Appendix B Informed consent form (Usability testers)

CONSENT TO PARTICIPATE IN THIS STUDY

I, ___________________ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had sufficient opportunity to ask questions and am prepared to participate in the study.

I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable).

I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my participation will be kept confidential unless otherwise specified.

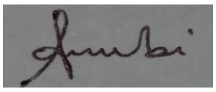
I agree to the completion of the questionnaire.

I have received a signed copy of the informed consent agreement.

Participant Name & Surname………………………………………… (please print)

Participant Signature…………………………………………..Date…………………

Researcher's Name & Surname…Olakumbi Anthonia Fadiran

Researcher's signature………  …………..Date…20th February, 2017

Appendix C Informed consent form (Learners)

CONSENT TO PARTICIPATE IN THIS STUDY

I, __________________ (participant's parent name), confirm that the person asking my consent for my child to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had sufficient opportunity to ask questions and am prepared to allow my child to participate in the study.

I understand that our participation is voluntary and that we are free to withdraw at any time without penalty (if applicable).

I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my child's participation will be kept confidential unless otherwise specified.

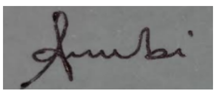
I agree to the completion of the questionnaire.

I have received a signed copy of the informed consent agreement.

Participant Name & Surname…………………………………………… (please print)

Participant Signature…………………………………………..Date…………………

Researcher's Name & Surname…Olakumbi Anthonia Fadiran

Researcher's signature………  …………..Date…20th February, 2017

Appendix D Questionnaires

D.1 Questionnaire for knowledge visualisation tool evaluation process

BACKGROUND
My name is Olakumbi Anthonia Fadiran, and I am conducting this research for my Master of Science degree at the University of South Africa (UNISA). It is aimed at understanding the criteria used in selecting the most appropriate tool for evaluating the use of knowledge visualisation in high schools. In order to collect data for this research, please answer the following questions. This should take approximately 40 minutes of your time.
INSTRUCTIONS
The document is divided into the following four sections:

SECTION	WHAT IS COVERED
SECTION A	Biographic details that gather certain characteristics about you, the participant
SECTION B	Pre-questionnaire input that gathers certain perceptions you have of using visualisation tools
SECTION C	Questionnaire prompting you to rate different types of visualisation tool in relation to knowledge visualisation guidelines
SECTION D	Post-questionnaire input that gathers certain perceptions you have of visualisation tools after going through the detailed survey

Please go through the sections and where relevant:

1.1 Mark your choice with an "X" in the box provided
1.2 Use the rating system provided in the section to indicate your preference in the box provided

1. Please note that some questions require a single response, while others may require multiple responses.
2. The input you provide will be treated confidentially and only used towards the completion of the afore- mentioned qualification.

Thank you, your co-operation is highly appreciated

SECTION A: USER PROFILE INFORMATION

1. Please indicate your age

24-27	28-30	31-35	Above 35

2. Please indicate your gender

Male	Female

3. Please indicate your home language

Afrikaans	English	Northern Sotho	Southern Sotho	Tswana	Zulu	Other

If other, please specify: ____

4. Please indicate your highest education level

Post graduate degree	
Degree or diploma	
Post-matric certificate	
Grade 12 (Matric)	
Other	

If other, please specify: ________________________________

5. Please indicate your employment status

Employed	Self-employed	Unemployed

5.1 If self-employed, please indicate for how long

0-2 years	3-5 years	5 years +

6. How long have you been using Information Technology devices (e.g. mobile phones, tablet, laptop, desktop computer etc.)?

0-2 years	3-5 years	5 years +

7. Please select the device(s) you frequently use. If other(s), please specify.

Device name	Usage frequency Most frequent ⟷ Not as frequent				
	1	2	3	4	5
Smartphone (e.g. iPhone, Blackberry, Lumia, etc.)					
Laptop/Notebook					
Desktop PC					
Tablet (E.g. iPad, Galaxy tab, etc.)					
Kindle					
Other(s)					

SECTION B: PRE-SURVEY INPUT

1. Have you ever used images to represent your work (such as sketches, graphs, charts, tables, pictures, animations etc.)?

Yes	No

1.1. If your answer is ‘Yes’ above, please indicate how often below:

Visualisation type	Usage frequency Most frequent ⟵⟶ Not as frequent				
	1	2	3	4	5
Sketches					
Graphs					
Charts					
Tables					
Pictures					
Animations					
Other(s)					

If other (s), please specify: ______________________________________

SECTION C: RATING OF VISUALISATION TOOL IN RELATION TO KNOWLEDGE VISUALISATION USABILITY PRINCIPLES

This section lists knowledge visualisation guidelines based on usability principles identified by the researcher in a literature study. Please read the statements below, and next to each guideline put a rating in the box which indicates how strongly you agree or disagree with how well the selected tool tested has conformed to these principles.
The rating system is as below:

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Agree	Strongly agree
1	2	3	4	5

TOOL A: PADLET						
1. LEARNABILITY						
		Rating				
		Strongly disagree				**Strongly agree**
1.1	The tool is easy to use	1	2	3	4	5
1.2	New users can easily master the system and begin to use it effectively	1	2	3	4	5
1.3	User can easily locate available actions	1	2	3	4	5
1.4	Most of the pages have appropriate ‘Help’ links	1	2	3	4	5
2. FLEXIBILITY						
		Rating				
		Strongly disagree				**Strongly agree**
2.1	Allow user to modify interface to suit their needs	1	2	3	4	5
2.2	Offer support for easy modification of images	1	2	3	4	5
2.3	Provides ‘accelerators’ (unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users)	1	2	3	4	5
2.4	Allow different ways to perform action	1	2	3	4	5
3. CONSISTENCY						
		Rating				
		Strongly disagree				**Strongly agree**
3.1	User interface is consistent in appearance (The same words and symbols are used to refer the same things throughout)	1	2	3	4	5
3.2	User interface is consistent in behaviour (the same actions are performed the same way, throughout the system)	1	2	3	4	5
3.3	The same concepts, words, symbols, situations, or actions refer to the same thing/can be done the same way	1	2	3	4	5

4. EFFECTIVENESS						
		Rating				
		Strongly disagree				**Strongly agree**
4.1	Offer support to achieve your goal (i.e. complete tasks)	1	2	3	4	5
4.2	Every icon on a page fulfils a purpose	1	2	3	4	5
4.3	Offer support for correcting error successfully	1	2	3	4	5
5. EFFICIENCY						
		Rating				
		Strongly disagree				**Strongly agree**
5.1	The task (diagram) was completed within a reasonable period of time	1	2	3	4	5
5.2	The task (diagram) required reasonable amount of effort to complete	1	2	3	4	5
5.3	Information in the navigational headings are grouped logically	1	2	3	4	5
5.4	The tool is capable of allowing people to carry out their work efficiently	1	2	3	4	5
6. SATISFACTION						
		Rating				
		Strongly disagree				**Strongly agree**
6.1	I found the tool easy to use	1	2	3	4	5
6.2	I found it easy to correct errors successfully	1	2	3	4	5
6.3	Rate the KV tool based on the following: 1 – very poor 2 - average 3 - above average 4 - good 5 – excellent	1	2	3	4	5

TOOL B: LIBRE OFFICE DRAW						
1. LEARNABILITY						
		Rating				
		Strongly disagree				**Strongly agree**
1.1	The tool is easy to use	1	2	3	4	5
1.2	New users can easily master the system and begin to use it effectively	1	2	3	4	5
1.3	User can easily locate available actions	1	2	3	4	5
1.4	Most of the pages have appropriate 'Help' links	1	2	3	4	5
2. FLEXIBILITY						
		Rating				
		Strongly disagree				**Strongly agree**
2.1	Allow user to modify interface to suit their needs	1	2	3	4	5
2.2	Offer support for easy modification of images	1	2	3	4	5
		Strongly disagree				**Strongly agree**
2.3	Provides 'accelerators' (unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users)	1	2	3	4	5
2.4	Allow different ways to perform action	1	2	3	4	5

3. CONSISTENCY						
		Rating				
		Strongly disagree				**Strongly agree**
3.1	User interface is consistent in appearance (The same words and symbols are used to refer the same things throughout)	1	2	3	4	5
3.2	User interface is consistent in behaviour (the same actions are performed the same way, throughout the system)	1	2	3	4	5
3.3	The same concepts, words, symbols, situations, or actions refer to the same thing/can be done the same way	1	2	3	4	5
4. EFFECTIVENESS						
		Rating				
		Strongly disagree				**Strongly agree**
4.1	Offer support to achieve your goal (i.e. complete tasks)	1	2	3	4	5
4.2	Every icon on a page fulfils a purpose	1	2	3	4	5
4.3	Offer support for correcting error successfully	1	2	3	4	5
5. EFFICIENCY						
		Strongly disagree				**Strongly agree**
5.1	The task (diagram) was completed within a reasonable period of time	1	2	3	4	5
5.2	The task (diagram) required reasonable amount of effort to complete	1	2	3	4	5
5.3	Information in the navigational headings are grouped logically	1	2	3	4	5
5.4	The tool is capable of allowing people to carry out their work efficiently	1	2	3	4	5

6. SATISFACTION						
		Rating				
		Strongly disagree				**Strongly agree**
6.1	I found the tool easy to use	1	2	3	4	5
6.2	I found it easy to correct errors successfully	1	2	3	4	5
6.3	Rate the KV tool based on the following: 1 – very poor 2 - average 3 - above average 4 - good 5 – excellent	1	2	3	4	5

SECTION D: POST SURVEY INPUT

1. Please indicate which of the two knowledge visualisation tools tested above you prefer

Padlet	
LibreOffice Draw	

i. Please elaborate why you selected this tool

ii. Please list additional usability functionality you feel should be present in the tool that wasn't mentioned in this survey:

iii. Do you think the use of knowledge visualisation has had any effect on your knowledge acquisition?

Yes	
No	

Please justify your answer below:

Thank you very much for your co-operation. Your input is greatly appreciated.

D.2 Questionnaire for effect of knowledge visualisation guidelines

BACKGROUND
My name is Olakumbi Anthonia Fadiran, and I am conducting this research for my Master of Science degree at the University of South Africa (UNISA). It is aimed at selecting the most appropriate visualisation tool based on usability principles, for the purpose of investigating how knowledge visualisation can be used by learners for knowledge internalisation and transfer. In order to collect representative data, I would like to ask you questions to analyse the impact of applying knowledge visualisation principles/guidelines on images produced. This should take approximately 50 minutes of your time.
INSTRUCTIONS
The document is divided into the following four sections:

SECTION	**WHAT IS COVERED**
SECTION A	Biographic details that gather certain characteristics about you, the participant
SECTION B	Pre-questionnaire input that gathers certain perceptions you have of using visualisation tools
SECTION C	Analysis of knowledge visualisation guidelines on images produced by learners
SECTION D	Post-questionnaire input that gathers your observation on the impact of applying knowledge visualisation guidelines on images produced by learners

Please go through the sections and where relevant:

1.1 Mark your choice with an "X" in the box provided.

1.2 Use the rating system provided in the section to indicate your preference in the box provided.

3. Please note that some questions require a single response, while others may require multiple responses.
4. The input you provide will be treated confidentially and only used towards the completion of the afore- mentioned qualification.

Thank you, your co-operation is highly appreciated
SECTION A: USER PROFILE INFORMATION

6. Please indicate your age

24-27	28-30	31-35	Above 35

7. Please indicate your gender

Male	Female

8. Please indicate your home language

Afrikaans	English	Northern Sotho	Southern Sotho	Tswana	Zulu	Other

If other, please specify: ________________________________

9. Please indicate your highest education level

Post graduate degree	
Degree or diploma	
Post-matric certificate	
Grade 12 (Matric)	
Other	

If other, please specify: ________________________________

10. Please indicate your employment status

Employed	Self-employed	Unemployed

5.1 If self-employed, please indicate for how long

0-2 years	3-5 years	5 years +

6. How long have you been using Information Technology devices (e.g. mobile phones, tablet, laptop, desktop computer etc.)?

0-2 years	3-5 years	5 years +

7. Please select the device(s) you frequently use. If other(s), please specify.

Device name	Usage frequency Most frequent ⟷ Not as frequent				
	1	2	3	4	5
Smartphone (e.g. iPhone, Blackberry, Lumia, etc.)					
Laptop/Notebook					
Desktop PC					
Tablet (E.g. iPad, Galaxy tab, etc.)					
Kindle					
Other(s)					

SECTION B: PRE-SURVEY INPUT

2. Have you ever used images to represent your work (such as sketches, graphs, charts, tables, pictures, animations etc.)?

Yes	No

2.1. If your answer is 'Yes' above, please indicate how often below:

Visualisation type	Usage frequency Most frequent ⟷ Not as frequent				
	1	2	3	4	5
Sketches					
Graphs					
Charts					
Tables					
Pictures					
Animations					
Other(s)					

If other (s), please specify: ______________________________________

3. What knowledge visualisation guidelines do you take into consideration when creating the images depicted above?
(Please tick as many as applicable)

Knowledge visualisation guidelines	Mark (X) on those applicable
Know your data: Designer must first understand and evaluate the content that is to be communicated through a visualization	
Know your audience: Take into account for whom the visualisation is intended	
Clarity: Images shown is not ambiguous	
Abstract (compress) the knowledge: concentrate on essence i.e. increase quality instead of quantity to prevent cognitive overload	
Present overview and detail: Present overview but include details on a lower level	
Be consistent: For example, elements such as colour, shape, size, symbols, and fonts should be similar for similar types of data in all visualizations	
Avoid decoration	

Use natural representations: i.e. visualisation can be associated with the real world	
Motivate audience: Visual representations should be designed to envision, to lead to thinking, and to encourage users to elaborate knowledge	
Know your data: Designer must first understand and evaluate the content that is to be communicated through a visualization	

3.1. Would you say the use of the knowledge visualisation tool (Padlet) can meet this guidelines when creating images to represent your work?

Yes	No

3.2. Please elaborate on your answer above

SECTION C: ANALYSIS OF KNOWLEDGE VISUALISATION GUIDELINES ON IMAGES
In this section, the images produced by learners will be evaluated before and after they have been briefed on knowledge visualisation guidelines. The number of learners that adhere to each guideline before and after the brief are noted as shown below:

Knowledge visualisation guidelines	Number of learners that adhered before knowledge visualisation guideline brief	Number of learners that adhered after knowledge visualisation guideline brief
Know your data: Designer must first understand and evaluate the content that is to be communicated through a visualization		
Know your audience: Take into account for whom the visualisation is intended		
Clarity: Images shown is not ambiguous		
Abstract (compress) the knowledge: concentrate on essence i.e. increase quality instead of quantity to prevent cognitive overload		
Present overview and detail: Present overview but include details on a lower level		
Be consistent: For example, elements such as colour, shape, size, symbols, and fonts should be similar for similar types of data in all visualizations		
Avoid decoration		
Use natural representations: i.e. visualisation can be associated with the real world		
Motivate audience: Visual representations should be designed to envision, to lead to thinking, and to encourage users to elaborate knowledge		

NATURE OF IMAGES CREATED		
Easy to understand		
Simplicity: Maximum 7 (plus or minus 2) objects on every level		
Content categories relevance: The framework captures key concepts and their relationships within the said domain		
Images: Thoughts and ideas are represented with standard/appropriate shapes to convey learning information		
Use of colours: Image created is colour coded i.e. the same colour is used for similar concepts		
Dual coding: Use of text and images to process information		
Consistency: colour, shape, size, symbols, and fonts should be similar for similar types of data e.g. same symbol is used for same concepts throughout		
Image size: This should be consistent with the size of screen		
Relationship between concepts clearly shown		
Clear boundaries: i.e. areas where events take place must be clearly stated where applicable		
Legend: Concise explanation of symbols used in a diagram		

SECTION D: EVALUATION OF THE APPLICATION OF KNOWLEDGE VISUALISATION GUIDELINES ON IMAGES PRODUCED

2. Please indicate if there are changes to the initial diagrams of learners after knowledge visualisation guidelines where applied

Yes	
No	

iv. Please elaborate on your answer below

v. Will you consider using knowledge visualisation as a means of exhibiting knowledge transfer to others?

vi. Do you think the use of knowledge visualisation has had any effect on learners knowledge acquisition?

Yes	
No	

Please justify your answer below:

Thank you very much for your co-operation. Your input is greatly appreciated.

D.3 Questionnaire for knowledge visualisation evaluation process (Learners)

QUESTIONNAIRE FOR KV MODEL EVALUATION

BACKGROUND

My name is Olakumbi Anthonia Fadiran, and I am conducting this research for my Master of Science degree at the University of South Africa (UNISA). It is aimed at using knowledge visualisation to demonstrate learner's knowledge acquisition. In order to collect data for this research, please answer the following questions. This should take approximately 40 minutes of your time.

INSTRUCTIONS

The document is divided into the following four sections:

SECTION	WHAT IS COVERED
SECTION A	Biographic details that gather certain characteristics about you, the participant
SECTION B	Pre-questionnaire input that gathers certain perceptions you have of using visualisation tools
SECTION C	Post-questionnaire input that gathers certain perceptions you have of the use of knowledge visualisation in secondary school

Please go through the sections and where relevant:

1.1 Mark your choice with an "X" in the box provided

1.2 Use the rating system provided in the section to indicate your preference in the box provided

5. Please note that some questions require a single response, while others may require multiple responses
6. The input you provide will be treated confidentially and only used towards the completion of the afore- mentioned qualification

Thank you, your co-operation is highly appreciated

SECTION A: USER PROFILE INFORMATION

11. Please indicate your age

12-15	16-20	Above 20

12. Please indicate your gender

Male	Female

13. Please indicate your home language

Afrikaans	English	Northern Sotho	Southern Sotho	Tswana	Zulu	Other

If other, please specify: ______________________________________

14. Please indicate your highest education level

Grade 8 - 9	
Grade 10 - 12	
Fresh Matriculant	

If other, please specify: ______________________________________

5. How long have you been using Information Technology devices (e.g. mobile phones, tablet, laptop, desktop computer etc.)?

0-2 years	3-5 years	5 years +

6. Please select the device(s) you frequently use. If other(s), please specify.

Device name	Usage frequency Most frequent ←→ Not as frequent				
	1	2	3	4	5
Smartphone (e.g. iPhone, Blackberry, Lumia, etc.)					
Laptop/Notebook					
Desktop PC					
Tablet (E.g. iPad, Galaxy tab, etc.)					
Kindle					
Other(s)					

7. Which of this device(s) is available for use in your school? Please select as many as are available

Device	**Availability**
Smartphone (e.g. iPhone, Blackberry, Lumia, etc.)	
Laptop/Notebook	
Desktop PC	
Tablet (E.g. iPad, Galaxy tab, etc.)	
Kindle	
Other(s)	

If other, please specify: ______________________________________

SECTION B: PRE-SURVEY INPUT

4. Have you ever used images to represent your school work (such as sketches, graphs, charts, tables, pictures, animations etc.)?

Yes	No

4.1.If your answer is 'Yes' above, please indicate how often below:

Visualisation type	Usage frequency Most frequent ⟷ Not as frequent				
	1	2	3	4	5
Sketches					
Graphs					
Charts					
Tables					
Pictures					
Animations					
Other(s)					

If other (s), please specify: ______________________________________

5. What visualisation tool do you use for creating the images depicted above? (Please list as many as you can remember)

a. ______________________________

b. ______________________________

c. ______________________________

6. Have you heard of the following visualisation tool?

Tool	**Yes**	**No**
Padlet		
LibreOffice Draw		

6.1. If you answered 'Yes' above, how frequent do you use this tool?

Visualisation tool	Usage frequency Most frequent ⟷ Not as frequent				
	1	2	3	4	5
Padlet					
LibreOffice Draw					

6.2. In what capacity did you use the tool mentioned above for your school work?

Yes	
No	

6.3. Please elaborate on your answer above

SECTION C: POST SURVEY INPUT

3. Please indicate if the use of knowledge visualisation guidelines had any effect on your final diagram

Yes	
No	

vii. Please elaborate on your answer below

viii. Will you consider using the guidelines mentioned above as a means of exhibiting knowledge transfer to others?

ix. Do you think the use of knowledge visualisation has had any effect on your knowledge acquisition?

Yes	
No	

Please justify your answer below:

Thank you very much for your co-operation. Your input is greatly appreciated.

Appendix E: Rocket launch question paper for learners

Name of participant: ……………………………………………….

Research topic: Using Knowledge Visualisation to Demonstrate Learners' knowledge Acquisition

Ethics clearance reference number: 023/OAF/2017/CSET_SOC

PLEASE READ THE FOLLOWING INSTRUCTIONS CAREFULLY

1. This questions paper must be written under examination conditions
2. Read the questions carefully
3. Answer all questions
4. Write in dark blue or dark pen
5. All diagrams are to be drawn using pencils or the recommended knowledge visualisation tool (Padlet)
6. You are reminded of the need for clear presentation in your answers
7. The total number of marks for this paper is 100
8. Answers to each question should be marked/written on the question paper
9. The input you provide will be treated confidentially and only used towards the completion of the afore- mentioned qualification
10. Time: 1 hour

Scores

Question	**Maximum**	**Score before knowledge visualisation presentation**	**Score after knowledge visualisation presentation**
Part A	8		
Part B	12		
Part C	20		
Part D	60		
Total	**100**		

Part A: Multiple choice questions

1. Any sample of matter has mass and takes up space. The main reason for this is because:
   a) All matter is heavy
   b) Matter can be a gas
   c) Matter is made up of tiny particles that have mass and take up space
   d) The Earth is made of matter

2. This matter has a fixed shape and volume with particles closely packed together with little movement. It is a:
   a) liquid
   b) solid
   c) gas
   d) plasma

3. Any man-made object sent in space to orbit around certain body is called
   a) geostationary orbit
   b) low earth orbit
   c) artificial satellite
   d) natural satellite

4. For every action there is equal and opposite reaction this was Newton's
   a) first law of motion
   b) second law of motion
   c) third law of motion
   d) all of them

5. A rocket moves forward when ____________ are expelled from the rear of the rocket.
   a) waters
   b) gases
   c) forces of gravity
   d) fuels

6.The three forces that act upon a rocket in flight are?
   a) weight, thrust and lift
   b) weight, thrust and drag
   c) airflow,weight and thrust
   d) thrust, drag and airflow

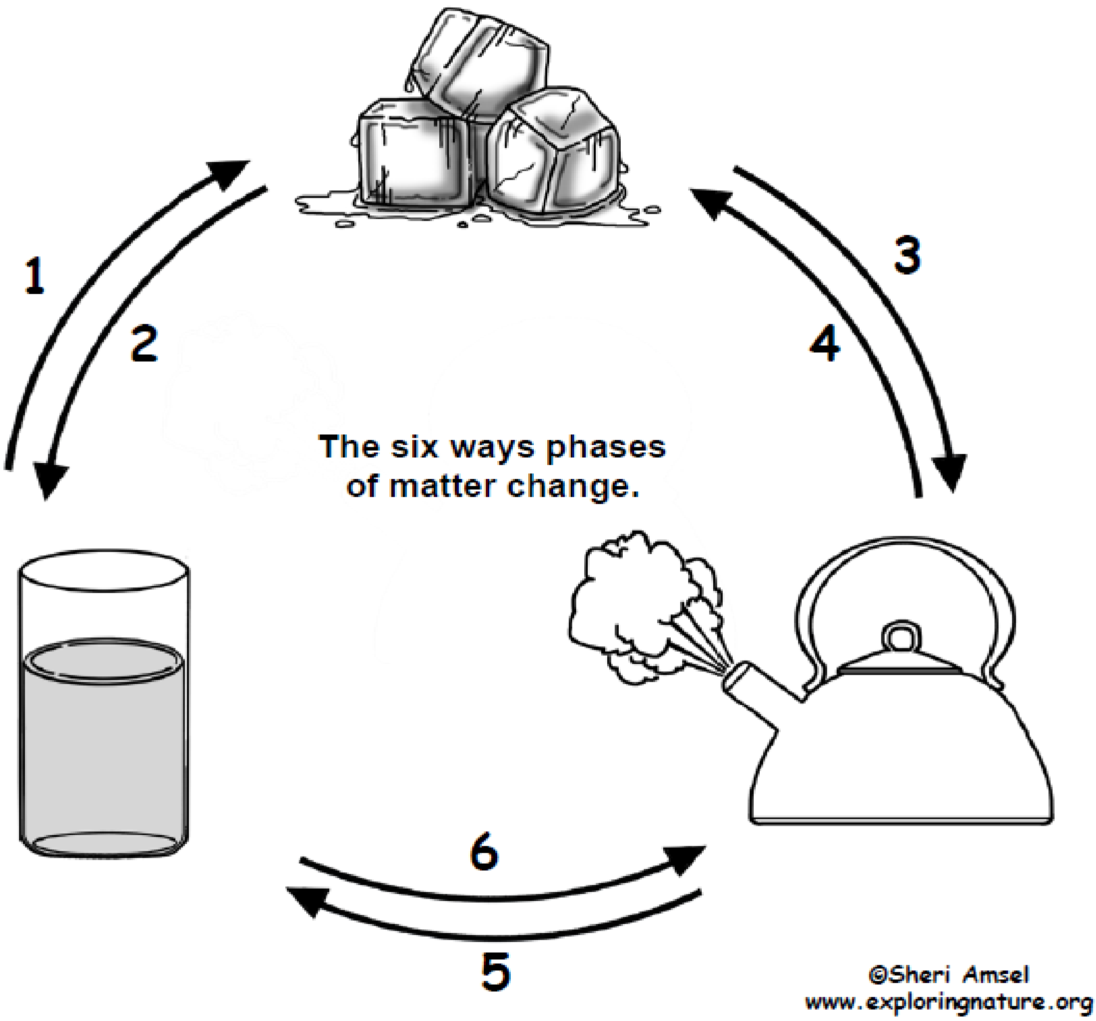
7. What is the unit of weight in the metric system?
   a) kilogram
   b) newton
   c) pound
   d) meters per second squared

8. The moon is a satellite.
a) True
b) False

[8 marks]

Part B: Label the following diagram

Phases of Matter



Name the six ways the phase (state) of matter changes:

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________

[12 marks]

Part C: Answer the following questions using the word bank provided.

Payload, Condensation, Apogee, Satellite, Rocket, Shape, Vaporisation, Matter, Water, Parachute, Thrust, Phases, Drag, Force, Solid, Streamer, Reaction, Coast Phase, Earth, Spacecraft, Lift, Human, Size

**Note that some terms may be used more than once and some not at all

1. The highest point in the trajectory of a rocket is called ___________________
2. ________________________ is the conversion of a vapour or gas to a liquid.
3. _______________________ is a force used to stabilize and control the direction of flight.
4. Anything that has weight and occupies space is referred to as __________________
5. Examples of payload are ___________________ and ________________________
6. At the recovery phase of a rocket launch, ____________________ can be used instead of a parachute
7. The boiling point of _________________________ is 100 degrees C
8. Factors affecting aerodynamics are _______________________ and ______________

[20 marks]

Part D: Design project

Using your knowledge of how rockets are launched, you are requested to make a **diagrammatic representation** of this process in a form of presentation for your school portfolio

Rubric for diagram

Criteria	Marks	Learner marks before knowledge visualisation presentation	Learner marks after knowledge visualisation presentation
Suitable title	5		
Labels	20		
Links	10		
Originality and creativity	20		
Neatness	5		
Total	60		

[60 marks]

Appendix F: Systematic Literature Review

Author and Date	Title	Research Question	Literature Theories or Models	Methodology	Limitations	Findings	Future research
(Sun, Li & Zhu, 2016)	Action Research on Visualization Learning of Mathematical Concepts Under Personalized Education Idea: Take Learning of Geometrical Concepts of Elementary Math for Example	(a) How can visualisation learning method support learning activity of geometrical concepts of mathematics? (b) What about the learning effects?	-	Action research: Five types of learning activities supported by different visualisation methods was proposed and applied in two rounds of action researches in learning geometrical concepts of elementary mathematics	The research was specific to the mathematical domain	Learning abilities in elementary mathematics can be improved via the use of visualisation	Researchers have paid more attention to the application of various visualisation methods (i.e. knowledge visualisation, thinking visualisation and data visualisation), giving little to the comprehensive application of visualisation methods in learning
(Ahmad, Ahmad & Rejab, 2011)	The Influence of Knowledge Visualization on Externalizing Tacit Knowledge	How can KV be used to convert lecturer tacit knowledge to student explicit knowledge in teaching and learning process?	Conceptual framework	Design-based research: A conceptual framework of KV was developed which provides an analytical perspective on externalizing tacit knowledge	The use of conventional teaching materials (e.g. lecture notes, slide presentations etc.) is not sufficient enough to increase a learner's understanding	KV can be used to convert lecturer tacit knowledge to student explicit knowledge in teaching and learning process	The conceptual framework proposed is tested by using Structural Equation Modeling (SEM). The result will be used to revise the conceptual model

Author and Date	**Title**	**Research Question**	**Literature Theories/ Models**	**Methodology**	**Limitations**	**Findings**	**Future research**
(Bertschi et al., 2011)	What is Knowledge Visualization? Perspectives on an Emerging Discipline	What is knowledge visualisation?	-	Case study: Expert opinions from members of the Advisory and review Committee of The International Symposium on Knowledge Visualisation and Visual Thinking was gathered reflecting on the current and future state of each individual's perspective on the notion of knowledge visualisation (KV).	-	Visualization improves communication, in particular the interaction around cognitive processes	The field of KV could benefit from: - studying and measuring its impact on collaborative interactions, groupware accessibility and social media - understanding the implications on input devices (e.g. multi-touch screens) as a form of interaction - testing on new domains such as intercultural communication - integration with Visual Analytics to build a simple and accessible means for analysing, evaluating and utilizing knowledge
(Gu, Ahmad & Sumner, 2010)	Improving Conceptual Learning through Customized Knowledge Visualization	How does KV improve learning experience?	Conceptual learner model	Design-based research: KV was used to utilize a conceptual learner model which was constructed using natural language processing techniques. This conceptual learner model helps learners to locate new concepts and to integrate them with their own knowledge.	The research gave a suggested learning path for learners to use as against giving room for diversity i.e. the variability of learner's literacy skills and learning styles	Despite the availability of numerous educational digital libraries, learners find it difficult to effectively locate and use these resources to fulfil their learning needs. The availability of this new and relevant information often leads to confusion as it does not commensurate with their prior knowledge. Also, information from various sources are sometimes inconsistent and incompatible	Because of the diversity in learner's literacy skills and learning styles, a study could be done on how to customize/modify learning paths (different from that which was suggested) and note the effects of such customization on the model proposed

Author and Date	Title	Research Question	Literature Theories/ Models	Methodology	Limitations	Findings	Future research
(Evert, 2015)	A Model Using Technologic-al Support for Tutors in Practical Computing Sessions	How can conceptual model of technology be used to support tutors during practical sessions in the Computing Sciences Department at NMMU	-	Design Science Research (DSR) methodology i.e. A conceptual model using technology to support tutors during practical sessions was designed and proposed based on features of the existing models.	The scope of the research project is limited to providing appropriate technological support to tutors of practical sessions at the CS department, NMMU alone. Thus, the results of the evaluation cannot be generalised	Tutors, students and lecturers found the tablet PC application useful and supportive. Tutors were pleased with the user interface, interaction and navigation while participating students agreed that the tool was useful in allowing tutors to answer questions easily, thereby allowing them to complete their work with ease	The tablet PC tool can also be extended to - cater for visualisation in form of videos - Enhance its current features such as the ability of students to view FAQ from other technological devices e.g. desktop computer, mobile phones etc. - make it more interactive between tutors and students The inclusion of multiple lecturer participants to determine their opinion of the lecturer chat application could be a benefit to the extension of study
(Wang et al., 2011)	Knowledge Visualization for Self-Regulated Learning	How KV can be used to ease the cognitive overload, conceptual and navigational disorientation experienced by learners when faced with large/vario-us information resource	-	Design-based research: An online learning platform “JAVA E-Teacher” was developed to demonstrate the effectiveness of using KV to incorporate visualised representations of domain knowledge structure into e-learning systems	The evaluation result is limited to a small sample size. More participants are needed to be able to generalise the results.	The system had a positive impact on student’s attitude towards online leaning as the JAVA e-Teacher was reportedly easy to use	The findings of the study gives a platform for further exploration with the system to determine its impact on reducing cognitive load and improving self-regulated learning process

Author and Date	Title	Research Question	Literature Theories/ Models	Methodology	Limitations	Findings	Future research
(Scarpato , Maria & Pazienza, 2012)	Knowledge-based visualization systems	How visualisation processes can be automated	-	Design-based research: A new approach to generate GUIs in semi-automatic way was proposed using the SAGG system for implementation. SAGG is a knowledge-based visualisation system that makes use of information supplied by users to automate the visualisation process.	Most existing knowledge-based visualisation applications work only on specific domains/tasks and thus cannot be generalised. Also, there is lack of automatization in the process of visualisation	Knowledge based visualisation approaches are associated with the following problems: - Graph-based scalability - Faceted browsing - Domain-specific - Widget-based	The SAGG system model could be - explored to combine several configuration files to generate more complex GUIs and possible specify the interrelationship between them - expanded to cater for more functions
(Eppler & Burkhard , 2004)	Knowledge Visualization - Towards a New Discipline and its Fields of Application	1. What type of knowledge is visualised? 2. Why should that knowledge be visualised? 3. How is the knowledge visualised?		Case study	Visualisation can have drawbacks with regard to specific contexts and also, there is the risk of possible distortion of reality through misinterpretations	KV presents an avenue to: - create new knowledge and enhancing innovation - solve predominant knowledge-relate problems in organisations - be used as an effective strategy against information overload	The following areas need to be investigated: - a comprehensive framework that focuses on knowledge-intensive visualisation is needed - how complementary visualisation can be of benefit - potential negative effects in authentic application contexts

Author and Date	Title	Research Question	Literature Theories/ Models	Methodology	Limitations	Findings	Future research
(Van Biljon & Renaud, 2015b)	Facilitating Knowledge Visualisation as Communication and Knowledge Transfer Mechanism in Postgraduate Learning	How can the production of knowledge visualisations be supported in a mobile learning context?		A faded-struts learning process that strategically removes instructional techniques/scaffolding as the learners become experts or more proficient in their field was used	KV is not without designer/user induced risks which can ultimately affect the cognitive, emotional and social human aspects of the communication process	Learners are often time the consumer of visualisation as against being the producers. There is need for them to become active participants in the creation of visualisation in order to improve self-regulated learning	Actively engaging learners in creating KV
(Azzouza, Azouaou & Ghomari, 2010)	Teacher's Knowledge Visualization Method (TKVM): A method and tool for school web sites knowledge cartography	How to discover a teacher's existing skill and knowledge via the school website	Reference model	Design-based research: A new method referred to as Teacher's Knowledge Visualisation Method (TKVM) was used to map teacher's knowledge together with the school's website content to create knowledge driven cartographies.	School websites generally contain knowledge that is informal and difficult to locate due to the large amount of information on each web page.	The use of ontology-driven visual cartographies can aid knowledge localization and also enable the processing of large collection of web pages within a short period of time	-

Author and Date	Title	Research Question	Literature Theories or Models	Methodology	Limitations	Findings	Future research
(Ahmad, Ahmad & Rejab, 2011)	The Influence of Knowledge Visualization on Externalizing Tacit Knowledge	How to measure the percentage of knowledge transfer from the lecture to the student? How to find a way to improve knowledge transfer? How to make learners able to successfully formalize the knowledge from the lecturer?	Conceptual framework	Exploratory research	Most of the knowledge transferred to learners is in tacit form and difficult to externalized. Also, the use of conventional teaching materials such as lecture notes, slide presentation is not enough to increase student's understanding	The study reveals that KV is one of the approaches to convert lecturer tacit knowledge to student explicit knowledge in teaching and learning process	The conceptual model will be reviewed based on findings of the initial test.

Appendix G: Publication from this research

How can visualisation principles be used to support knowledge transfer in teaching and learning?

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Abstract— **Visualisation has proven benefits in supporting knowledge transfer. Furthermore, it can enable learners to become co-creators rather than only consumers of knowledge. Technological advancements have made visualisation more accessible as a mechanism to improve teaching and learning but theorisation and best practices are lacking. This study aims to investigate the usefulness of knowledge visualisation principles for improving knowledge presentation and demonstrating knowledge transfer by high school learners. A design-based research methodology is applied which required the creation and evaluation of guidelines (artefacts) in order to assess the effects of knowledge visualisation principles while visualising. The results indicate that some of the knowledge visualisation principles extracted from literature could improve knowledge transfer in secondary school education. The contribution of this paper is to propose a set of validated knowledge visualisation guidelines towards the theory and practice of using knowledge visualisation in teaching and learning.**

Keywords— ***Knowledge visualisation, knowledge visualisation principles***

1.0 Introduction

Modern technology opened many possibilities to using visualisation for educational purposes. An important role of a teacher is to aid the transfer of knowledge to students in a way that is meaningful and understandable [1]. The teacher uses his/her expertise to select and use teaching materials such as textbooks, lecture notes, multimedia resources etc. to assist in this role [2]. Teachers also employ specific strategies to support knowledge creation and transfer, and one of such strategies is visualisation [3]. Visualisation entails using images to communicate data, however, teachers, educational, learning and instructional designers are often the ones creating these visual images for teaching and learning [4] with little or no input from learners. According to [5], learners should be co-creators of their learning experience rather than having knowledge merely made available for learners' consumption.

For the scope of this research, the focus will be on the usefulness of knowledge visualisation principles for secondary school learners to construct, demonstrate and internalise the new knowledge that they are expected to master. The ability of learners to acquire, assimilate and sort knowledge plays an important role in their learning process as learners are unique in the manner they absorb, process and store information. To internalise knowledge, learners have to engage in its creation [5].

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To explore how knowledge visualisation principles can be used for improving knowledge presentation and transfer by high school learners in a way that the teacher can assess the student's understanding, a group of high school learners were asked to create visualisation models to explain the process of a rocket launch. Learners were then exposed to knowledge visualisation principles and the initial images produced were updated to accommodate these principles. The goal of the exercise was to investigate the effect of each principle on the images produced by the learners and how the principles have helped improve their knowledge representation towards demonstrating their knowledge acquisition.

The rest of the paper gives a brief insight to what knowledge visualization entails and the degree of compliancy by learners on knowledge visualization guidelines. This is useful in selecting and prioritising knowledge visualisation principles for this group.

2.0 Literature review

Manovich [6] defined visualisation as the conversion of measurable data into a visual representation. Visualisation is further explained as the use of images to represent spatial and non-spatial variables in a manner that reveals its patterns and relations [6–8].

2.1 What is knowledge visualisation?

Knowledge visualisation according to [9] is the act of representing complex concepts and data using graphics and animations in ways that people have not seen before, in order to aid knowledge transfer and creation. Zhang et al. [1] and Burkhard [10] explained knowledge visualisation as the act of exploring the use of visual representations such as graphs, diagrams, drawings, sonographs etc. to enhance knowledge creation and transfer between at least two people. For [11], it is a process that entails various steps such as gathering, interpreting, developing, understanding, designing and sharing information. Eppler [12] relates the term to the use of graphics to create, integrate and administer knowledge. Van Biljon & Renaud [13] noted that the primary aim of knowledge visualisation is *knowledge transfer* whereas that of information visualisation is to support *pattern identification*. In summary, knowledge visualisation entails the creation of knowledge, using available visual resources in a manner that is understandable and communicable to other people.

2.2 Knowledge visualisation principles

A systematic literature review (SLR) process was used to gather design guidelines from the field of information and knowledge visualisation. The SLR was selected as a protocol that is claimed to be replicable, transparent, objective, unbiased and rigorous [14–16]. The databases used are IEEE Xplore, Google Scholar, Scopus, Springer and ACM, and the search strings used are those that returned results containing at least one of the terms knowledge/information visualisation, knowledge/information visualisation principles, knowledge/information visualisation guideline. The search was conducted between February and October 2017 for English papers published in conferences and journals.

Table 1 is a matrix table that gives a summary of knowledge visualisation principles from literature that can be used to improve images produced for knowledge representations.

Table 1: Knowledge visualisation principles from literature

Knowledge visualisation guidelines	Description	Author(s)
Abstract (compress) the knowledge	Extracting essential components and their relationships from a body of knowledge.	[17–21]
Present overview and details	'overview' gives a context information of the field while the 'detail' gives more information about a part of the overview.	[20, 23, 24]
Consistency	The use of visual elements such as colour, symbols, shapes etc. should be the same for the same kinds of information.	[24, 25]
Easy to understand	Presenting visualisation in a clear, comprehensive way makes it easy to understand, such that little previous knowledge of the content is required.	[26, 27]
Know your data	A designer must first understand and explore the data domain in order to create images that are meaningful and relevant.	[24, 26]
Clarity	The use of defined symbols to avoid ambiguity.	[25, 28]
Know your audience	The designer should consider for whom the visualisation is intended e.g. an individual, a group, a network etc.	[29]
Use natural representations	Associating visualisation with real world allows a recognition-based approach to interpreting images instead of one that requires recall.	[30-33]
Legend	An accompanying item which: provides detailed explanations on symbols used, can become a control panel for making changes and provide multiple views onto data.	[20, 34]
Use of colours	To: specify a format that is applicable to a set of instances, differentiate relationships, beautification, grouping, mapping and classifying images.	[18, 24, 35, 36]
Avoid decorations	The use of irrelevant elements may distract the audience from the content of the topic	[25, 32]
Relationship between concepts clearly shown	Relationship between concepts can be illustrated using links	[28, 38]
Motivate audience	To enhance learning engagement	[39, 9]
Simplicity	Minimizing the number of concepts in each level of visualisation to 7±2 objects .	[28]
Dual coding	Using both textual and visual representation to process information.	[40–42]
Clear boundaries	To help with navigation and enclosing knowledge within a specific domain.	[43]

3.0 Research methodology

A design-based research methodology was applied to this study as it identifies with real world situations [44]. To create the knowledge visualisation models (artefacts) for the design-based research, a research group comprising high school learners and teacher was created and structured as a way to gather information about the impact of knowledge visualisation principles for supporting knowledge transfer. The method was used because it facilitated interaction between teacher and learners and enabled us to obtain qualitative and quantitative information from participants easily.

3.1 Procedure

The study was conducted at the Rooihuiskraal Library, Pretoria and participants were provided with computers with internet connection. There was a total of 22 participants (19 learners, 1 educator, 1 usability tester and 1 researcher). The 19 learners (6 females) are high school learners randomly selected from various schools in Pretoria, Gauteng. This is to ensure a cross-section of participants were selected as advocated by [45].

The group session began with a standard introduction and explanation of the purpose of the research. The participants were taught on 'How rockets are launched' and later asked to give a diagrammatic representation of the topic. After the first image was produced, learners were exposed to knowledge visualisation principles (as stated in Table 1) and were required to apply this principles to the initial image produced. This resulted in some learners modifying the old image while others produced a new image. The two images produced by each learner was then compared and evaluated based on the given knowledge visualisation principles. Quantitative analysis was conducted on knowledge visualisation principles by comparing the level of compliance before and after being exposed to these principles while qualitative analysis was carried out on both knowledge visualisation principles that were not measured and general observations during the session.

4.0 Results

Table 2 shows the percentage level of compliance by learners before and after they were taught on knowledge visualisation principles. The analysis was carried out on the measurable knowledge visualisation principles.

4.1 Analysis

Fig. 1 shows the percentage change in compliance of learners after being briefed on what knowledge visualization entails.

While some learners felt the need to produce a completely new visualisation that will accommodate the guidelines, others were able to edit their initial diagram. Overall, only few did

Table 2: Percentage level of compliancy by learners before and after the brief on knowledge visualisation principles

	Know your data		Abstract knowledge		Clarity		Avoid decoration		Use of natural representation		Easy to understand		Simplicity		Use of colours		Clear boundaries		Legend		Relationship between concepts shown	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Yes	22%	94%	72%	89%	78%	100%	89%	94%	61%	56%	17%	94%	89%	100%	11%	39%	11%	44%	0%	44%	61%	94%
No	78%	6%	28%	11%	22%	0%	11%	6%	39%	44%	83%	6%	11%	0%	89%	61%	89%	56%	100%	56%	39%	6%
% Increase in compliance	72%		17%		22%		5%		-5%		77%		11%		28%		33%		44%		33%	

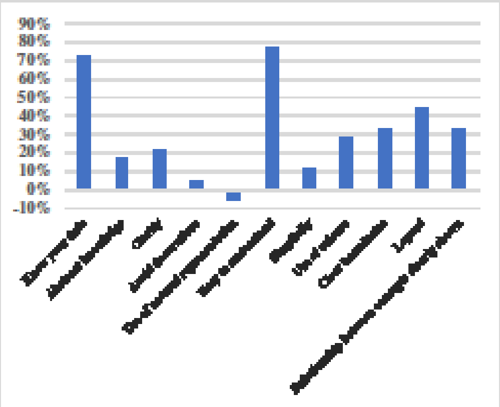

Fig. 1: Percentage increase/decrease in compliance

not feel the need to make any adjustment to their diagrams.

The before and after images of each learner was compared and below is a summary of the observations.

5.0 Findings

Fig. 2 below show samples of some of the learners' visualisation before and after the brief on knowledge visualisation principles. The figure reflects some of the observations noted in subsequent sections. In the first example, more information is added in terms of content and structure (relations between components). In the second example, a title is added to the visualisation (easy to understand), together with a description of the symbols used (legend). The former considered a visualisation to be a central picture and the guidelines led to fragmentation. Obviously, that should not be at the expense of coherence so the unintended consequences of the guidelines need to be monitored throughout.

5.1 Guidelines with noticeable influence on final diagram

The following guidelines had a percentage influence on the final diagram ranging from 22% to 77% compliancy level: Know your data, Clarity, Easy to understand, Use of colours, Clear boundaries, Legend and Relationship between concepts clearly shown.

None of the learners added a legend in their initial visualisation. However, after the brief, 44% of the learners felt there was a need to give a meaningful explanation of the symbols used by adding a legend thereby aiding other knowledge visualisation principles.

Clear boundaries may be subject to the context of the topic being visualized i.e. it is less applicable when the visualisation is within the same domain.

The high level of compliance for the 'Easy to understand' guideline was influenced by the compliancy of other guidelines, indicating inter-guideline dependencies.

Although there was a percentage increase of 28% for the use of colours after the brief on knowledge visualisation principles, a number of participants were cautious in the way they implemented this principle so as to avoid compromising other principles such as 'avoid decorations'. For others, it was a quick way to implement the principle on 'clear boundaries'.

5.2 Guidelines with little or negligible influence in final diagrams

The guidelines: Abstract knowledge, Avoid decorations and Simplicity had compliancy levels ranging from 5% to 17%.

From observation, 89% of the learners created a visualisation void of symbols whose meaning was not related to the content of the study.

Thus, the 'avoid decorations' principle did not make a substantial difference in the final images produced by the learners, especially after a legend was added to give meaning to symbols used. Also, the 'abstract knowledge' and 'simplicity' principles did not create much impact on the final images produced by learners.

For the former, this may be because of time constraint thus making learners include the most important point before the time for the test elapse while the nature of the topic being visualized may account for the latter.

5.3 Guideline with a drop in the percentage of compliance (Use of natural representation)

Learners in the research group did have personal preferences when using visualisation to represent knowledge. While most agree that using images to represent and transfer knowledge is a field they are willing to explore, others have expressed their reservations on the use of images to represent their knowledge. The latter believe that to implement knowledge visualisation, you must be artistically inclined. In view of these, there was a 5% drop in the compliance level for

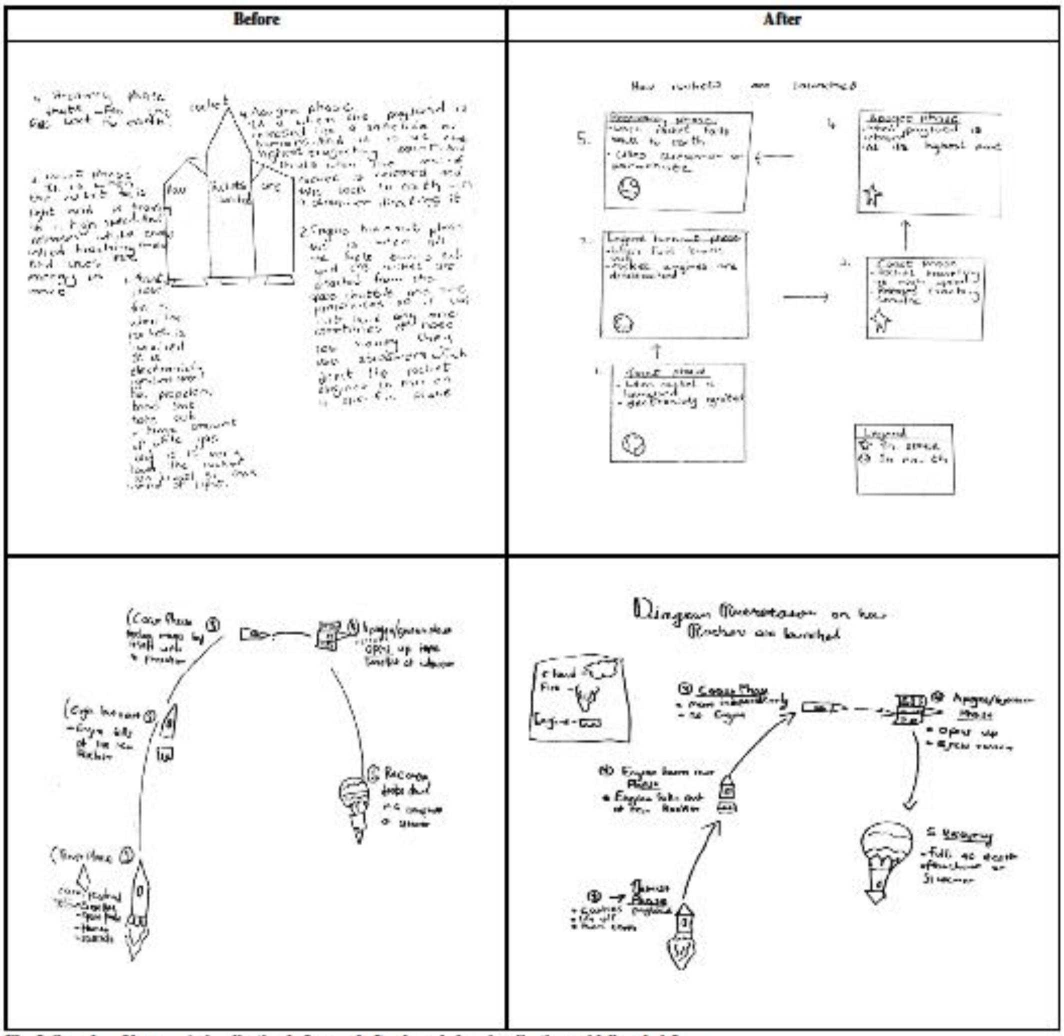

Fig. 2. Samples of learners' visualisation before and after knowledge visualisation guidelines brief

participants who expressed their concern that their representation of the real world may be violating another principle i.e. avoid decorations. Furthermore, it is argued that the use of natural representation can be subjected to the designer's background. For example, the use of fire to represent volcanic eruption in the geographical field may be seen as heat in the chemical field.

5.4 Guidelines that may have been difficult for the focus group to understand and implement

Learners found the 'Motivate audience' guideline difficult to implement. Some of the questions raised were: whether to make the images produced very attractive, add a motivational paragraph in form of an introduction to the diagram or produce images that speak to a particular audience. However, the learners argued that implementing these suggestions may compromise some of the learnt principles such as abstracting the data, avoid decorations etc.

5.5 Guidelines that were difficult to measure

The guidelines: Know your audience; Consistency; Motivate audience; and Dual coding were explained to the learners but the visualisation were not evaluated thereof.

5.6 Guidelines that were easier to implement electronically than on paper

The execution of the 'Present overview and detail' principle was more easily implemented by most learners electronically than on paper. Devices used for visualisation e.g. desktop computers, laptops etc. usually have inbuilt technologies that makes it possible to zoom in on a particular section of an image, accounting for this. However, it is important to note the issue of usability in e-learning where there is the need to first know how to use the application [51].

5.7 The execution/effect of one guideline on another

The execution of some guidelines increased the conformity of others. In essence, some guidelines were observed to be inter-related as the execution of one gives credit to the implementation of another. Examples are:

- Legend (clarity, easy to understand, consistency)
- Easy to understand (simplicity, abstract the data, avoid decorations)
- Avoid decoration (Legend)

6.0 Factors that may have influenced learners' conformity to knowledge visualisation guidelines before/after brief

Various factors may have influenced learners' compliance with knowledge visualisation guidelines either before or after the brief. This includes aspects such as providing a rubric for the diagram, information overload, and the time constraint. In addition, knowledge-based visualisation applications work only on specific domains/tasks and thus cannot be generalized [18, 37, 46, 47, 48]. There is also the risk of possible distortion of reality through misinterpretations [48]. The diversity in learners literacy skills and learning styles also affect how knowledge visualisation can be used for teaching and learning [49]. The lack of automatization in the process of creating knowledge visualisation [18] and the constraints of the mobile technology platform on which knowledge visualisation can be implemented e.g. connectivity, power, size of screen, memory etc [13] may have played a role. The high tendency to provide too much information to learners during teaching and learning may also have led to disorientation and cognitive overload [50].

7.0 Conclusion and Future work

This paper discussed how knowledge visualisation principles could provide support in improving knowledge transfer amongst high school learners. The findings indicate that most of the principles considered in this study provided various degrees of impact on the images produced by learners. While some made significant impact, others' impact could be considered negligible. This allows prioritization of the knowledge visualisation principles, for the context of high school learners.

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