UNIVERSITY OF THE WITWATERSRAND

The Missing Link: How ICTs Contribute to Retention of Mathematical Concepts. A Conceptual Study

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DECLARATION

I declare that this research report is my own unaided work. It is submitted for the degree of Master of Education at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination to any other university.

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Benson Munyoro July 2020

The research has been submitted with my approval as a University of Witwatersrand supervisor.

Signature---------------------------------Date:---

Dr Reuben Dlamini

University of Witwatersrand

DEDICATION

This Master's report is dedicated to my mother and late sister. These two special people believed in me and pushed me to excel. They sacrificed much to enable me to get a good education. I also wish to dedicate this report to my grandmother Anna, who took care of me when my mother could not. For believing in me, I thank you.

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I thank the different persons and officials who made the variety of documents I required for my research available.

I thank all members of the faculty for the constructive criticisms that helped me make numerous amendments to the initial document. In the process I've learnt much and gained many virtues that forever transformed me as a person.

My heartfelt gratitude goes to my family, especially my wife and children, who had to deal with my frustrations and sometimes lack of motivation to complete the research.

Last, but not least, I would like to thank the Almighty God without whom I would have long given up on this research.

ABSTRACT

Numerous reports, such as the Trends in International Mathematics and Science Study (TIMSS) reports have shown that South African learners have been struggling in mathematics education. Perkins (1991) listed the three goals of (mathematics) education as retention, understanding and application. Education, which is used interchangeably with learning in this research, refers to the process whereby learners understand, retain and apply mathematical concepts. Therefore, poor achievement in mathematics education is in essence a failure to understand, retain and apply concepts. Retention, a core category studied in this research, is considered not only an educational goal but also important in making further learning in mathematics, possible.

I decided to focus on retention, even though it is just one of the three goals of education because my observations over many years of teaching mathematics, confirm its centrality in the subject. It has also been quite evident from this research, that learners often struggle with concepts, even ones they initially demonstrated an understanding in. It was noted that generally, learners tend to do very well in assessments administered soon after a lesson but struggle with the same concepts if they are asked to demonstrate an understanding later in a delayed assessment, a phenomenon that was also observed by Kang (2016).

While much research has been done that generally points to the inadequate pedagogical and content knowledge of teachers, especially in South Africa (Venkat & Spaull, 2015; Bowie, Venkat & Askew, 2019; Bansilal, 2015; Taylor, 2019), this research's view is that delayed assessments are responsible for students' low performance in the subject. Comparing assessments administered close to when the concept was taught and end of term and year exams confirm the negative impact of delayed tests on mathematics performance. This confirms the importance of retention, and that although many learners understand mathematical concepts, they fail to retain that understanding for a long time which in turn hampers further learning (Karagiorgi & Symeou, 2005; Wilson, 2009). Quite often, the failure to retain concepts is often confused with a failure to understand concepts, especially in delayed assessments. Although these two goals are related, they need to be viewed as separate but connected entities. Retention of concepts, which is defined collectively by its indicators discussed in the research, plays an integral role in supporting mathematics, which in the present research is hierarchical, sequential and connected (Wilson, 2009). In turn, a number of authorities have flagged Information and Communication

Technologies (ICTs) as affording practices that enhance retention (Ferriman, 2014). So, although this conceptual paper will study the importance of this goal in mathematics education, it will also focus on how ICTs promote retention with the intention of constructing a pedagogical framework guiding ICT integration in the subject. This focus gets support from Kennewell (2006) who argued that (technological tools) will not act independently of pedagogical settings in which they are used and that an evaluation of the impact of ICT on teaching and learning, requires an "…accompanying detailed analysis of the complete pedagogical setting" (p. 102).

ICT affordances must, therefore, be viewed in terms of their impact on indicators of retention within specified pedagogical contexts. Indicators of retention are practices and behaviours that enhance retention. Certain technological tools and certain uses of these tools and software tend to predispose some of these technologies to an advantage over others in enhancing and supporting retention of mathematical concepts.

A conceptual study was used in this research because it allowed the research to reinterpret existing data to bridge the gap between existing major concepts, categories, theories and models in order to offer new insights and support inferences from existing literature and documents that broaden the current pedagogical thinking on ICT integrated mathematics learning (Gilson & Goldberg, 2015). Conceptual papers, by their very nature do not follow the status quo (Gilson & Goldberg, 2015), as will be seen in this research, usually because their thrust is to solve practical problems through the delineation of constructs, premises, assertions and reinterpretations from a variety of theories and data that converge around the topic. The simplicity in which this research is presented is deliberate. It is meant to make its adoption easier in order to improve mathematics performance.

A grounded theory methodology was used to study the following four main categories, with ICT and retention being the core themes of this research: ICT affordances; the nature of mathematics; the function of retention in mathematics; and the enabling pedagogical framework that leverages the potential of ICTs to support the retention of concepts. Initially, all the above four above categories were studied separately, but thereafter, were systematised into a pedagogical framework. During data collection and analysis, the silo approach of studying the categories was not always sharply defined and linear, as evidenced by the many back and forth connections with other categories that formed the basis of discussions where clear links existed and permitted it.

The research started with skeletal low level and emergent categories on the nature of mathematics and the category of retention. These emerged from the initial engagement with literature in the literature review section. Thereafter, a semi-structured discussion strategy on sources was adopted to approach the data collection with these skeletal low level and emergent categories being utilised as ‘lenses’ to guide the initial stages of collecting data and analysis. This process culminated in the categories being further refined and developed and prepared them to build inter-category connections necessary to construct a suggested framework.

The nature of the research required me to make interpretations and reinterpretations and necessitated the extensive use of metaphors. The metaphors of building and blocks were used not only to show a hierarchy, but also the sequence and connections implied in the nature of mathematics taught in Finland, and the official books and curricular from South Africa and Zimbabwe. Other metaphors used relate to tentacles and hooks that all signify the importance of connections and in certain instances, highlight conceptual disconnections in learners’ conceptual understandings as a result of pedagogies that obliviate learners’ current and previous learning experiences and skills.

While initially I had hoped to confirm that ICT tools are mainly learning tools, a study of data sources indicated that their abilities to keep records and provide feedback at the click of a finger makes them invaluable teaching tools that support retention as well.

Among others, the recommendation that stands out in this research is that the nature of mathematics demands individualised attention and that teaching and learning should be differentiated based on learners’ prior available (retained) understandings. Retention itself is an individualised process that depends on and build upon each learner’s previously retained concepts. The multiple processes required to cater for different learning styles and paces in order to democratise mathematics learning requires the careful use of ICT tools, whose potential affordances allow them to function as an assistant teacher and make processes that would ordinarily be impossible, possible. ICT tools effectively used while catering for differentiated learning becomes invaluable tools of inclusion, especially of learners who were not previously catered for in a classroom where the teacher focuses on the average, and not those who are considered outlier learners.

The research concludes by putting the various elements of low level and emergent categories together to construct a pedagogical framework that guides teachers on the use of ICTs to enhance the retention of mathematical concepts. This new framework, which is currently not in existence, constitutes what has been referred to as the 'missing link' of the research.

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ABBREVIATIONS AND ACRONYMS

CAI:	Computer Assisted Instruction
CAPS:	Curriculum Assessment Policy Statement
DoE:	Department of Education
ICT:	Information and Communication Technologies
IWB:	Interactive White Board
PC:	Personal Computer
TIMSS:	Trends in International Mathematics and Science Study
ZAD:	Zone of Actual Development
ZPD:	Zone of Proximal Development

CHAPTER 1: INTRODUCTION

1.1 **Introduction and Background**

The socio-economic and scientific development of any nation is heavily dependent on its technological and scientific progress, and mathematics plays a key role in this (Lawal, 2013). This subject is an important and indispensable component of the school curriculum, playing an integral role in developing higher order thinking skills needed to achieve "… the outcomes and developing skills such as conceptualisation, generalisation and information processing" (Nieuwoudt, 2006, in Cassim, 2010, p. 1). Norris (2012) argued that Mathematics is needed in the sciences and provides access to undergraduate courses such as engineering and sciences. It is also necessary for a range of life skills, including choosing mortgages and financial investment options. The performance of learners in Mathematics in South Africa has, however, been a cause for concern given that the subject underpins abstraction and problem solving (Vorderman, Porkess, Budd, Dunne, & Rahman-hart 2011), which are core life skills regardless of one's occupation.

Trends in International Mathematics and Science (TIMSS) for 2015 showed that for Grade 9, South Africa was 38th out of 39, and for Grade 5, 47th out of 48 countries. The Programme for International Student Assessment (PISA) results for 2015 again showed the same worrying trend with South Africa coming 75th out of 76 participating countries (Marius, 2018). The results indicate that only 1% of learners in South Africa, compared to 54% of Singaporean students, achieved an advanced pass.

Table 1-1 Summary of South African performance in 2015 TIMSS (National Advisory Council on Innovation, 2016)

International Benchmark	Grade 5 Mathematics	Grade 9 Mathematics	Grade 9 Science
Advanced (>625)	1%	1%	1%
High (550–625)	4%	3%	4%
Intermediate (475–550)	12%	10%	9%
Low (400–475)	22%	21%	18%
Potentials (325–400)	28%	35%	28%
Not Achieved (<325)	33%	31%	40%

More than 80% of the learners performed below the intermediate level. This is worrying! Table 1-2 below shows the low results in Grade 9 Mathematics and Sciences in the now discontinued annual national assessments (ANA), suggesting a strong positive correlation between these two subjects and that a poor performance in Mathematics has a negative impact on the Sciences.

Table 1-2 Summary table for Mathematics and Home Languages Annual National Assessments averages for Grade 3, 6 and 9 (Adapted from the Department of Education [DoE], 2012–2014 report)

	Literacy/Languages Average Pass			Numeracy/Mathematics Average Pass		
Grade	**National Average**			**National Average**		
	2012	2013	2014	2012	2013	2014
3	52%	51%	56%	41%	53%	56%
6	43%	59%	63%	27%	39%	43%
9	43%	43%	48%	13%	14%	11%

The Annual National Assessments results shown in Table 1-2 confirm that learners are facing greater challenges in Mathematics than in languages, especially in the higher grades; hence, the need to explore how different countries and teachers practically understand the unique nature of the subject.

Much research has been done on the problem of mathematics education in South Africa. This include research by Venkat and Spaull (2007), focussing on teachers' content knowledge in the subject, which produced some very worrying results. Few research, if any, have been done to verify the extent to which the current Mathematics curriculum relates to the requirements of Perkins' (1991) three goals of education, especially retention. The constant evolution of Information and Communication Tools (ICTs) and how they mediate learning, necessitates a further study on their contribution to retention of mathematical concepts. This gap made this qualitative research, using grounded theory to explore and gain a deeper understanding on the subject, necessary.

The goals of education, including mathematics education, are retention, understanding and application (Perkins, 1991). Perkins defined understanding as "… the ability to think and act flexibly with what one knows" (p. 40). Retention, one of the axial categories of this research, refers to medium- to long-term semantic and declarative memory for prior and foundational mathematical concepts and skills, as well as the ability to retrieve key facts about a concept (not just mere word for word recitation) after a period of two or more weeks (medium- to long-term) with the intention of problem solving or generating new knowledge. Retention is defined in detail in Section 1.2. Application was explained by Perkins, (1992, p. 2) when he said "in a sense, any learning requires a modicum of transfer", and is essential to extend knowledge, demonstrate understanding or solve problems. The three goals of learning are actually the three low levels on Blooms Revised Taxonomy, and recall is at the bottom, followed by understanding and application (Anderson & Krathwohl, 2001). It is an intriguing question whether Perkins was suggesting that we should only go as far as the third level on the revised taxonomy and leave out the rest. This research argues that Perkins's goal of application was rather broad and encompasses analysis, evaluation and creation, because these three levels are dependent on, or emerge from, learners' prior skills and knowledge.

The importance of the three goals in mathematics education is aptly described by Dror (2008, p. 216) who posited that "… learning takes place when the cognitive system acquires *(encodes), understands* and *keeps (retains)* information for *further use*" (researcher's emphasis), as shown in Figure 1-1. Although the definitions of the three goals all have elements of application, Dror's (2008) definition separates these into three distinct entities. He further argued that if this process is not successful, learning would not have taken place. Successful mathematical education only happens if learners understand, retain and apply concepts to solve problems or extend learning (Dror, 2008; Perkins, 1991). If that is the case, the aim of all progressive teachers should be presenting concepts in such a way that learners understand, retain and use them to solve real life problems in different contexts.

Laurillard (1993) agreed and further posited that technological affordances have the potential to enhance the attainment of the goals, hence the current focus on ICTs. It was the need to establish the truth of this rather sweeping statement that created the need for further examination in the research. Supporting Laurillard's assertion, Ferriman (2014) explained that online learning approaches have a greater likelihood of hitting on a variety of learning styles, impacting positively on retention. The current focus on retention and enabling technological external conditions (ICTs) necessary for learning mathematics has mainly been derived from Perkins (1991), Dror (2008) and Laurillard (1993), supported by Ferriman (2014).

This research tried to show that Perkins's (1991) goals that he identified 30 years ago are still relevant. The small number and clarity of the goals made me optimistic that improved performance in mathematics is attainable and only requires a small shift in the way the subject is being taught. The poor performance in mathematics today, especially in South Africa (National Advisory Council on Innovation, 2016), could therefore be seen as a failure to achieve understanding, retention and application of concepts. A focus on retention was necessitated by my observation that not only is retention a goal of mathematics education, but that retained concepts promote further understanding and support application. While the adoption of the three goals might prevent us from attaining the higher levels of mathematical conceptions of developed countries, it offers a simpler step-by-step approach that can be easily adopted to immediately improve performance in the subject. Its elements pervade the other two goals by affecting and being affected by them.

Figure 1-1 shows a functional but non-linear relationship among the three goals of education. Concepts that have been retained enhance further conceptual understanding and make successful knowledge transfer possible. In the current research, application refers to all forms of knowledge transfer, including problem solving, using in a new lesson and higher levels from level three on the revised Blooms Taxonomy.

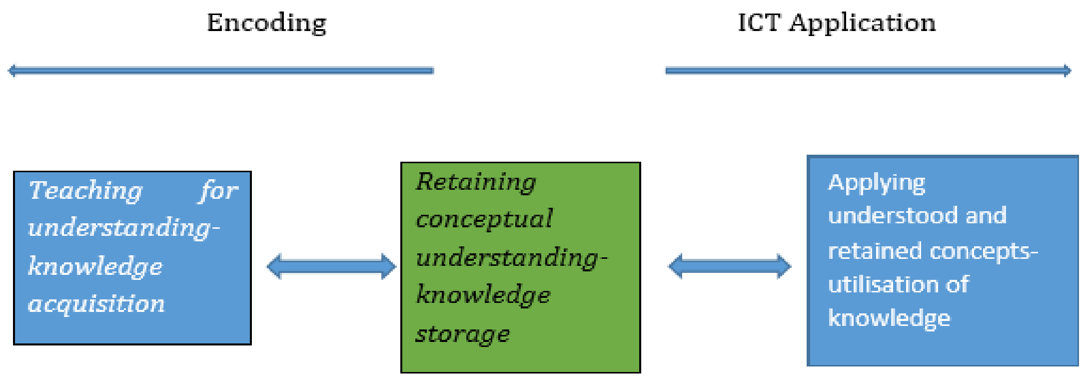

Figure 1-1 Memory cycle built on three basic processes showing the reciprocity of Perkins's (1991) three goals of education. Retained concepts support both the application of known concepts and act as a firm foundation on which to build further conceptual understanding. (Adapted from Feldman, 2006, p. 213; Dror, 2008)

Perkins's (1991) listing of retention as one of the three important goals of education finds impetus from Piaget in Hammond, Austin, Orcutt and Rosso (2001), who proposed a balance between the role of memory and free activity in learning that varies from subject to subject. He argued that, "Generally speaking … every discipline must include a certain body of acquired facts"

(p. 6). In relation to the goals of education, the following scenarios are observations that characterise my view of how mathematics is currently being taught in South African schools:

1. Teaching through rote and drill approaches. This approach puts very little emphasis on understanding. Learners are taught to regurgitate mathematical information, and any deviation in questioning or context tends to leave them confused. The approach is mainly characterised by low order questions that mainly test recall of facts. Learners taught using this approach struggle with high order and open-ended questions and are also likely to struggle in situations that require mental effort and creativity (Neisser, 1982).
2. Teaching for knowledge acquisition with little or no opportunities for retention of concepts. The teacher's main focus is ensuring that learners understand the concepts. Teachers are content with the high achievement in tasks that immediately follow lessons. Delayed assessments often show the weaknesses of this method, with major complaints by teachers using this approach being that while learners demonstrate competence in class, they tend to forget concepts as evinced by diminishing performance over time (Kang, 2016). Even a comparison on achievement in grade assessments that does not acknowledge the impact of timing of the assessments would produce inaccurate results.
3. A thrust towards application and problem solving with little emphasis on retention. This approach negatively impacts on scaffolding that relies on the existence of prior knowledge (Karagiorgi & Symeou, 2005). Proponents of this approach focus on problem solving, but problems often arise when learners become frustrated and struggle to complete tasks successfully because they lack the requisite prior knowledge and skills to complete the tasks. This approach is another source of negative attitudes about mathematics, because in their quest to teach higher maths, teachers leave a 'trail of gaps' in learners' conceptions of the subject. Using the analogy of building, this can be likened to someone trying to suspend a brick in the air and claim to have made huge progress.
4. A variety of combinations of the above in varying degrees is evident in some classes where teachers make an effort to teach for understanding, ensure that the concepts are retained and are applied to solve high order problems (Kang, 2016).

Pedagogical deficiencies, especially in the first three approaches listed above, are possibly a result of being unaware of the existence and interconnections among the three goals of learning, resulting in learners labelling mathematics 'difficult'. These problems, especially in relation to supporting retention of mathematical concepts, can be mitigated by integrating ICTs in learning (Laurillard, 1993). Because the efficacy of ICTs depends on a variety of factors (Kennewell, 2006), their advent in most schools requires a pedagogical shift and framework to systematise and guide teachers on how to use their immense potential to enhance the retention of concepts. I feel that this guiding framework is still missing in the current literature, hence the need for this research. The recommended framework has been arrived at through a thorough study of the interaction among the four low-level selected categories (inferred from the topic), which are the nature of mathematics, retention, ICTs and pedagogy, which are discussed further in Sections 2.1 to 2.3.

1.2 **Clarification of Terms**

Retention of learned information is defined by Bennett and Rebello (2012) as "…having the information stored in long-term memory in such a way that it can be readily retrieved, for example, in response to standard prompts" (p. 167). Hughes (2018) defines retention as "the fact of keeping something in one's memory." I find Hughes's definition rather limiting in view of the fact that it lends itself closer to rote methods of teaching and does not make reference to the retrieval process, which is of central importance to this research. Bennet and Rebello's (2012) definition closely describes this research's view that retention is a process of storing concepts that is preceded by a firm understanding making them retrievable as resources for further transfer or application.

The category of 'retention' includes within it the sub-categories knowledge storage, long-term memory and internalisation. In this report, Perkins's goal of retention varies from retention of a single item to thousands of items before they are affected by decay and interference. The concepts of recall and memory are also sub-categories of retention, but these words are used sparingly because of their association with the traditional approaches of drill and rote learning, where the focus is memorisation rather than understanding. In this research, retention as a goal happens at micro and macro levels, from a single learning episode to a series of learning episodes, and to lifelong learning.

The term 'concept' in this research refers to mathematical concepts, skills, attitudes and knowledge.

'Learning' or 'education' simply refers to mathematics learning.

‘Prior’, ‘existing’ and ‘foundational’ concepts refer to retained concepts. In the literature review these terms are compared to the zone of actual development (ZAD) (Section 2.2).

‘ICT tools’ refer to both the hardware and software components of technology. In this research, the hardware under study are the laptop, interactive white board (IWB), iPad, tablet, television and calculator. The software under study are mainly MyPedia and Mathletics, a programme that is used extensively in most countries to support mathematics learning. The distinctions between the tools are more emphasised during the simultaneous process of data collection and analysis.

1.3 **Government Policy on ICT Integration**

The South African Department of Education (DoE), through its ICT in education policy, the White Paper on e-Education (DoE, 2004), developed guidelines for Teacher Training and Professional Development in ICT (DoE, 2007) as well as “… guidelines for the distribution and use of digital resources in schools at school level” (Ndlovu & Lawrence, 2012, p. 2). Although these are recommendations and evidence of government’s will to integrate ICT in schools, these are neither subject nor lesson specific and do not address the ‘how’, which can only be addressed by the envisaged framework. Again, the impact of ICTs on the retention of mathematical concepts and related pedagogical practices in the classroom has not yet been fully defined and established. The wide variety of educational tools themselves, without the aforementioned pedagogical framework, would leave most novice and average teachers confused about how ICTs can be used to support mathematical learning.

1.4 **Justification of a Conceptual Study**

A conceptual study allowed me to explore how the nature of mathematics affect pedagogy as well as bridging the effects of existing cognitivist concepts on retention and technological affordances. It also allowed a description of the interaction between the categories in a learning space that is best explained by constructivist theories. The main purpose was to offer new insights and broaden the current pedagogical thinking (Gilson & Goldberg, 2015). This is particularly important for this type of research where different schools of thought converge, such as cognitive and constructivist concepts. Conceptual research provides the flexibility to conceptualise a new framework for integrating ICTs in mathematics education that guides and supports the way technologies are used in education.

I envisaged that the synthesis of knowledge from previous studies and other documents would lead to the emergence of a new pedagogical framework on ICT integration in mathematics education. Factors and pedagogical contexts that impact on successful ICT mediated learning, especially for sequential and hierarchical mathematical topics, are too numerous to delineate at this juncture; hence, I considered the conceptual approach ideally suited to explore the currently hazy, but fundamentally connected, ideas related to this topic.

I evaluated the claims made in this paper on the basis of Toulmin's (1958) framework, (Figure 3-5) on whether they were understandable, have been substantiated and are of considerable significance. The criteria were also used to justify the elimination and inclusion of certain sources used in this research. It is on this basis that certain positions in the literature review in the studied papers were used to enrich this paper.

1.5 **Outline of Dissertation**

The first part of the dissertation gave a brief outline of the problems related to mathematics in South Africa, retention and government policy on ICT in education, and a brief justification for a conceptual study.

The next sections in Chapter 1 focus on the problem statement, the research aims and objectives, rationale for this study and a further explanation of the grounded theory method used in this qualitative research. The first section of Chapter 2 focusses on the relevant literature review of the major identified categories that address the research questions, after which a conceptual framework guiding this research is discussed. The literature in Chapter 2 is the basis on which the study of papers and documents in Chapter 4 was conducted. Chapter 3 deals with the research design and methodology. Data collection and analysis were mostly done simultaneously in the first four sub-chapters of Chapter 4. Chapter 4 is divided into five sub-chapters, with each of the first four focussing on one category. Chapter 5 focusses on the synthesis of the findings of the other chapters, and Chapter 6 is a discussion chapter and gives the recommendations for a new pedagogical framework on the use of ICTs to enhance the retention of concepts. Chapter 7 is the conclusion of the study.

1.6 **Problem Statement**

The following observations about the issues that have not yet been fully studied are pertinent in articulating the problem statement of this research.

Evidence presented in Table 1.1 and 1.2 indicate that most learners are struggling with mathematics. Using Perkins's (1991) view on the goals of learning, another way to put it would be to say challenges in mathematics are a result of a failure to understand, retain or apply mathematical concepts. Assuming that the three goals of education equally contribute to mathematics achievement, a very simplistic analysis would suggest that learners who lack conceptual retention start their mathematics education with the possibility of losing no less than a third of their marks. Furthermore, retention has a reciprocal relationship with the other two goals of education, further impacting on learners' problem solving skills and conceptual understanding. Claims have been made that ICT tools have the potential to enhance the retention of concepts (Laurillard, 1993; Punla &Teacher, 2014), but very little research has been done to establish the veracity of these claims.

A related problem, as indicated by the Grade 6 and 9 Annual National Assessments results in Table 1-2, is that general mathematics achievement is marginally lower than that in other subjects such as English. I assumed this could be due to the unique nature of the positivist mathematical subject that is objective, connected, hierarchical and sequential (Chinn, 2000; Wilson, 2009). This signifies the importance of prior or retained knowledge, and it becomes important, therefore, to establish not only the role of retention in facilitating learning, but also the function of modern and ubiquitous technological tools in the amplification of practices that enhance the goal. The research sought to evaluate documents that would describe in practical terms the teachers' practical view of the subject of mathematics.

The third problem is the process of demystifying the Everest Syndrome view of ICTs in mathematics learning that is based on an assumption that all technologies are inherently beneficial to learning (Gambari, Shittu, Ogunlade & Osunlade, 2017). While this could be indeed true in some instances, these assumptions are, however, not always accurate. Hamat and Embi (2010) argued that "online tools are often designed with a technology-driven view rather than a learning one" (p. 237), and so without an appropriate pedagogical context (one of the categories to be studied), as is currently the case, ICTs in schools might actually be detrimental to performance in the subject (Clarke & Svanaes, 2014).

Another problem closely related to the above is the current bunching together of ICT tool efficacy based on a false assumption that they all possess inherently similar affordances that make them equally beneficial. Chinn (2000) explained the differences in ICT tools by categorising them into games that offer practice, programmes that do mathematics, programmes that are just books, and programmes that teach mathematics. While it is tempting to think that programmes that teach mathematics promote retention, we should not forget that mark reports indicate otherwise. It is possible to demonstrate an understanding of concepts and yet forget that understanding in a matter of hours or days. It seems to be rather the type, not the mere activity of teaching or tool, that ultimately impacts on retention. It is necessary to establish the types of ICT tools that possess the best potential to support retention of mathematical concepts based on their perceptible and hidden affordances (Gaver, 1991) or prior creative use as demonstrated in past research, while being cognisant of the fact that the success of ICT tools depends on a variety of factors (Kennewell, 2006). Therefore, I am of the view that using ICTs in mathematics without an understanding of the interactions within the four low-level and emerging higher level categories is likely to become an expensive distraction rather than an aid to mathematics learning.

Finally, recommendations on technologically mediated learning have for a long time been disjointed with numerous assumptions and piecemeal solutions being suggested. Considering that a lot of companies are developing learning technologies and schools are investing in ICTs to improve results, there is a need, now more than ever before, to develop a pedagogical framework that give better recommendations on how ICTs can be used to promote retention of mathematical concepts.

The issues raised above, though linked, are numerous and complex. This difficulty was the basis for the rationale for selecting a conceptual approach using grounded theory methodology to gain a deeper understanding of the interaction between the identified research categories that address the research question.

1.7 **Research Aim**

The main aim of this research was to draw insights from primary and secondary sources towards the construction of a pedagogical framework guiding the effective use of ICT tools to enhance the retention of mathematical concepts.

1.8 **The Objectives of the Study**

Each of the objectives was linked to one of the four low-level categories of this research, which was also linked to the four sub-questions.

The objectives of the study were:

1. To establish the nature of mathematics.
2. To establish the importance of retention in mathematics education.
3. To establish how the use of ICTs contributes to the retention of mathematical concepts.
4. To provide a pedagogical framework for using ICTs to support the retention of mathematical concepts.

1.9 **Research Questions**

1.9.1 Main Question

To what extent are ICT tools enhancing the retention of mathematical concepts?

1.9.2 Sub-Questions

1. What is the nature of mathematics?
2. What is the role of retention in mathematics education?
3. Which ICT affordances enhance the retention of mathematical concepts?
4. What is the pedagogical framework that supports the use of ICTs to enhance the retention of mathematical concepts?

1.10 **Rationale for the Study**

I am aware that by focussing on retention, the study runs the risk of being accused of creating a back door entry for traditional rote and drill methods of teaching mathematics, which is why, although recall and memory are elements of retention and part of what the research is about, the terms were used sparingly. I am also aware of the possibility of being criticised for including four categories that seem to be mutually exclusive. Morales (2006), however, submitted that a gap or a missing link, which in this case is an absence of a pedagogical framework that link these seemingly unrelated conceptions, in literature provides opportunities for such research. This missing link can only be uncovered through a thorough understanding of the nature of mathematics, the role of retention in the subject, ICT affordances, and practices that support technology use in a mathematics classroom. The study has been motivated by the fact that although it has been acknowledged that knowledge is constructed on learners' entry level skills and knowledge (Karagiorgi & Symeou, 2005) and that ICTs enhance retention, a study on the pedagogical context that makes this possible and on how these views interact has not yet been done. The inclusion of the four distinct categories was therefore a deliberate effort to look at the topic from all four relevant viewpoints, after which areas of convergence and relationships would be identified and systematised to answer the research question.

Past research papers are generally silent on the goals of education in general and on the importance of retention of mathematical concepts, in particular. This could be related to a lack of awareness of the existence of goals and how they influence mathematics pedagogy, or a lack of awareness of the unique nature of mathematics as a subject. Again, in spite of the excitement about the introduction of technology in education, very little research on how ICTs can be used to support retention of mathematical concepts has been done. This could once again be the result of a lack of knowledge of the limitations of certain technologies or how they afford, or hinder, the retention of concepts. Claims have been made on how ICTs improve mathematics education (Punla & Teacher, 2014), but current literature has not yet sufficiently established the veracity of these claims, especially in relation to retention of concepts. This research is probably a pioneering endeavour to explain the role of retention in mathematics education and how affordances of certain ICTs within a certain pedagogical setting enhance the retention of mathematical concepts. The research has the dual function of advocacy for retention and the potential of ICT tools to support this goal; hence, the status of these two categories being axial in the research.

While the research sought to offer insights and thick descriptions of the enabling pedagogical settings that make it possible for ICTs to support retention, practical pedagogical considerations and limitations of certain ICTs should also be established. For example, while it is often claimed that learning ICTs afford a variety of activities such as active, collaborative and authentic learning that lead to generative knowledge, (Merrill, 1992). Karagiorgi & Symeou, (2005, p. 123) argued that “technology built on the assumptions of ‘pure’ extreme constructivism is extremely hard to conceive”.

1.11 **Limitations**

Due to practical considerations, the research was unable to study and make recommendations on all ICTs or pedagogical settings. In terms of ICT tools, the research focussed on video contexts, the iPad, the tablet, the calculator, and to a limited extent, the IWB, MyPedia and Mathletics software. The sheer amount of information required to provide details on each ICT tool would have made this paper an impossibility. A broader, rather than a detailed perspective was therefore adopted in the recommendations.

Again, the inductive nature of grounded theory made it difficult for the paper to uncover elements of subjectivity of the writers and researchers whose documents and papers were reviewed in the generation of data and findings. It is acknowledged that especially with brochures meant for marketing and school documents there is the possibility of subjectivity.

Purposive sampling of documents used for data collection may also have had a negative impact on the representativeness of conclusions reached in this research. It is also acknowledged that there are other factors, such as attitudes to ICT uptake and other extraneous factors, that are important but were outside the scope of this paper.

Lastly, the topic has so many ‘loose but linked’ ends (some of which could not be explored to saturation, although that was the initial intention) that required exploration through a grounded theory method. A failure to pursue all emergent higher level categories because of the practical considerations of time, scope and length may negatively affect the validity and reliability of the research findings.

1.12 **Research Methodology**

The constructivist grounded theory method was used to generate a new pedagogical framework on how ICTs can be used to enhance the retention of mathematical concepts. The rationale behind the selection of the constructivist grounded theory was that it allowed me to move “grounded theory methods further into the realm of interpretive social science …” (Charmaz, 2006, p. 521). The interpretative strategy that was adopted to study the selected papers and documents with the adapted basic features of grounded data that guided this research were the following:

1. Identification of low-level categories and emerging higher level categories from literature for retention that would be used as ‘lenses’ through which to evaluate the other categories.
2. Simultaneous collection and analysis of data
3. Creation of higher level categories and coding of data
4. Discovering processes and patterns in the data
5. Inductive construction of abstract categories
6. Writing of analytical memos between the process of coding and writing
7. Presentation of low-level and emergent categories in sub-chapters
8. The integration of categories into a pedagogical framework (Dey, 1999)

The four selected low-level categories were used as the initial structure to initiate the research. These emerged from the four research objectives and sub-questions that all addressed the main research question. Both these categories and other higher level categories that emerged through engaging with the data were further refined until new categories ceased to emerge or a stage of (theoretical) saturation was reached (Dey, 1999).

The rationale for the constructivist grounded theory was that most of the raw data and documents required for my research were already available. I opined that a deeper engagement, reinterpretation, comparison and discussion of existing data would result in the emergence of new patterns from existing sources that would in turn become the basis of a new pedagogical framework. Minnaar (2011, p. 88) explained that the role of a constructivist grounded theory researcher is “… translating what has been written by other researchers (and recorded by teachers, in this instance, on the four categories) for the purpose of revealing similarities and differences, and developing practice guidelines or theoretical concepts on a specific phenomenon”. What has been written by other researchers is not restricted to research findings, but includes facts and claims that are backed by authoritative sources that also form the basis of literature reviews in selected researches. The four categories were used as the basis to form the proposed pedagogical framework. The research simultaneously collected and analysed data on a theme-by-theme basis for the research papers and selected documents. Lesson plans were analysed section by section to study how the four categories are addressed in lessons. Although the research questions and the nature of mathematics described in this paper were suggestive of an empirical approach, they were actually described qualitatively.

1.13 **Philosophical Foundation**

The nature of the research topic highlighted some convergence between social and cognitive constructivist theories and how they interact to influence mathematics education pedagogy. This is supported by Cohen and Siegel's (1991) view that the study of psychology should not be either or, but a combination of both social phenomena and internal cognitive processes (social and cognitive constructivism). Cohen and Siegel's (1991) view justifies my position that both the cognitivist construct of retention and the constructivist view of technologies interact within a common phenomenon. In their own words, "… behaviour is not simply a product of environmental contingencies nor is cognition an antiseptically clean execution of internal processes" (p. 17). It is both. It becomes vitally important to understand the epistemological underpinnings of ICT related theories and their influence on the process of ICT mediated instruction. This includes the role of technological tools as explained by constructivist theories as well as the memory processes, including retention, that are aptly explained by cognitivist frameworks.

The following constructivist constructs are essential for this research: The ZAD that refers to prior or retained skills, and the zone of proximal development (ZPD) that can be simply viewed as the learning space between the acquired knowledge and skills (Kennewell, 2006), the envisaged goals within a lesson, or the entire learning life. Kennewell (2006) explained that learning should be characterised by the ways in which this learning space is bridged by learners with the help of teachers and technological tools. The learning space is to Kennewell (2006) what the ZPD is to Vygotsky (1978). The term ZPD would be more preferable in this study because it not only clearly suggests a movement of a (retained) concept from one level of abstraction to another within a pedagogical space, but also the connections between past, present and future learning experiences. That movement happens at micro levels such as a single lesson and at macro levels that can include the learning space between Grade 1 and 12. It is important to note that the macro spaces are composed of numerous, interconnected micro spaces. Reference to Vygotsky

(1978) is therefore premised on the view that the ZPD is that space where learning takes place through the mediation of ICTs, as cultural tools. The role of the tool and the teacher as the more capable other in facilitating conceptual connections cannot, therefore, be overemphasised.

CHAPTER 2: LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

The structure of the literature review in this section allows for a deeper understanding of each of the four major low-level categories that address the research topic, objectives and questions. An understanding of each of the categories led to and guided a further understanding of how each of the components fits into the 'jigsaw puzzle' of ICT mediated retention of mathematical concepts that was assembled at the end of the research in the form of a new pedagogical framework. Together, the four categories clarified how teachers practically view mathematics, how retention occurs and its function in mathematical education, and the pedagogical setting that potentiates the best use of ICTs to enhance the goal. The four low-level categories that were studied to address the research topic are:

1. The nature of mathematics
2. Retention in mathematics education
3. The ICT affordances
4. Pedagogical settings that lead to the effective use of ICTs to support retention.

Literature on the above four categories was used during data collection and analysis of texts to guide and act as lenses through which selected documents and texts were evaluated. Criticism of my approach can come in the form of using preselected low level categories later during data collection and analysis. However, it has to be borne in mind that these categories are not predetermining the research findings. They are only providing a skeletal structure and lenses through which data is evaluated.

2.1 The Nature of Mathematics

The discussion on the nature of mathematics, which addresses the first research objective and research question, is important because it justifies the need for retention in mathematics education. This category is important in this research because the way mathematics is viewed determines the way it is taught. While there are many views of what the subject should be, the general view is that of an objective, positive, hierarchical and sequential subject (Chinn, 2000). This theoretical view, which was subjected to scrutiny based on the observations made of analysed teaching and learning documents during grounded theory data collection and analysis, is suggestive of a conceptual hierarchy based on prior knowledge and connections as the basis for further knowledge construction, further justifying the importance of retention in mathematics education (Chinn, 2000; Wilson, 2009). Wilson (2009, p. 41) viewed foundational concepts as “the (elementary) building blocks of all higher mathematics”. Such a hierarchy is dependent on prior or retained concepts. Wilson further highlighted the extraordinary importance of the elementary school teacher in teaching not only the recall, but the understanding and application of number facts, the place value system, whole number operations, fractions and decimals, as well as problem solving. He further observed that with increasing levels of conceptual complexity, those who start with a successful understanding and retention of foundational concepts are usually far ahead of their struggling counterparts.

It became necessary to establish how different educational systems operate and function to ensure that learners are equipped with the foundational skills necessary for further learning. Together with this, an exploration of pedagogical practices, and especially, the way ICT tools are used to leverage the learning process was considered important. Wilson’s (2009) view suggests the need for a ubiquitous existence of Perkins’s goals at all levels of learning, from a single lesson to a series of lessons. Thus, from the first time learners encounter mathematics, emphasis should be placed on whether they understand what they are doing, whether they retain what they learn, and whether they are able to apply what they learnt in different contexts. This study sought to establish from available literature and documents whether curriculum and other pedagogical documents confirm the view that mathematics that is being taught in schools is indeed connected, sequential and hierarchically structured.

The nature of mathematics in this research was mainly described on the basis of the studied documents consisting of the curriculum documents, lesson plans, assessment documents, learners’ work and other relevant documents to ensure that there is a balance between the official and the practical view. The main reason for this was that the practical understanding of mathematics by teachers and the actual nature of mathematics taught in schools is confirmed not by policy or theoretical documents, but by observable pedagogical and related practices accompanying daily learning. The nature of mathematics as summarised by the selected three listed sub-categories listed below should lead to an understanding of how policy and teachers perceive the subject, which in turn impacts on practices and the selection of tools to teach the subject. The rationale for using the sub-categories listed below to evaluate documents is premised not only on the assumption that it is the former category each time that uses and supports retention, but that it promotes the other two goals of education as well (Chinn, 2000; Wilson, 2009). At both curriculum and implementation levels, the research sought to establish whether the nature of mathematics was:

1. Sequential versus non-sequential
2. A hierarchical view versus a horizontal view (that topics can be taught one after another without the need to build onto any foundation)
3. Connected versus non-connected

I argue that the policy and teachers' view of mathematics has a bearing on the emphasis put on retention, the selection of tools and the pedagogy practices that support the connections, sequencing and hierarchy of concepts.

Where there were observed discrepancies between curriculum documents and classroom practices, the nature of mathematics was described at both policy level and on the basis of documents that demonstrated the teacher's practical understanding of the nature of the subject. The next section focusses on the nature and function of retention in sequential, hierarchical and connected mathematics education.

2.2 **Retention**

Before exploring how ICTs enhance the retention of mathematical concepts, it was essential to embark on an in-depth study on the function and mechanics of retention, especially as it related to mathematical education.

Neisser (1982) pertinently asked, "... shouldn't memory have something to do with the past and isn't education what is left over when you have forgotten what you learnt?" (p. 57). If indeed this is true, a lot more effort is needed to ensure that learners retain as much of what they learn (and understand) as possible. Retention itself, cannot be reduced to recall, which does not work in the long term, as seen by the low performance in delayed tests by learners taught through rote. Sustainable retention cannot and should not be divorced from the other two education goals.

Retention is one of the four low-level categories of this study that addresses the second research objective and sub-question. Retention is seen in this research not only as a goal but also as facilitating successful mathematical learning, as will be further explained. There have been claims, however, that focus or even a talk about retention has no relevance in the current modern approaches of mathematics teaching. Because of the limited scope of this paper, those arguments were not pursued and only literature relevant to the current focus was considered. The starting premise of this paper was that retention, especially in mathematics learning, is not only important but integral to successful performance.

Maffei and Marriotti (2007) argued that it is difficult to do away with the memorisation approach in teaching. Strangely, while some strategies such as mnemonics have long been used and accepted as enhancing retention, especially in languages and arts, these are usually frowned upon in mathematics education. One cannot help but wonder if the retention techniques used in the languages are not the real reason behind the generally good performance in the subjects (Table 1-2). The importance of retention in learning was excellently described by Neisser (1982) who said that cognition includes all the processes by which the concepts are transformed, reduced, elaborated, internalised and retrieved. Retention and retrieval are part of cognition and in the absence of these two processes, cognition becomes insufficient.

Retention is both a lifelong and a short-term educational goal (Newman & Holzman, 1995; Perkins, 1991) that happens in the short- and long-term memory and survives beyond a learning episode and test taking (Wilson, 2009). Using this argument, it can be concluded that the approaches used in teaching for tests and assessments have been some of the greatest impediments to conceptual retention. Wilson's (2009) conceptualisation of the function of retained foundational concepts can best be explained by the retention metaphor.

2.2.1 The Retention Metaphor

The following house metaphor illustrates the importance of retention and the role of ICTs in the learning process. The analogy of the house is symbolic of the fact that teaching, just like building, is an art and a very creative process. The bricks, connected by mortar, can be used in a variety of ways and yet retain the character of each individual builder.

Mathematics learning can be likened to the process of constructing a house (Figure 2-1). Retained mathematical concepts are the building blocks (Wilson, 2009). The blocks should be available before any building can take place. Bricks need to be strong and should not crumble or 'disappear' if they are to be successfully used to build a house. ICTs act as the kiln and conveyor through which the blocks are strengthened (retained and evolved) and transported for use.

During this process, bricks improve the construction process and are also improved themselves as constituent parts of a 'block of blocks' (the two states) (Engestrom, 2010; Wilson, 2009).

Figure 2-1 Retention metaphors

Retained concepts, referred to as building blocks by Wilson (2009), are made stronger through the use of ICTs, resulting in improved subsequent retention as evidenced by the block of blocks that is bigger than the initial block as illustrated in Figure 2 .1 above. The strength of the block of blocks depends on the strength of the connections between the individual blocks. When retained concepts are connected to new concepts, there is growth. In real building, single blocks are laid one at a time, but mathematics education is connected, sequential and hierarchical, and concepts evolve, grow and are eventually connected as blocks of blocks. This is why Wilson (2009) pertinently observed that with increasing levels of mathematical conceptual complexity, those who start with a successful understanding and retention of foundational concepts are usually exponentially ahead of their peers.

A word of caution: Retention without an understanding of mathematical concepts is different from and should not be equated to intelligence, because that becomes rote learning, which at best could be regarded as memorisation or recall. In his account of Shass Pollaks who could memorise thousands of pages of the Talmud but lacked any scholarly grasp, Neisser (1982) dispelled the extreme and ever peddled assumption that memorisation on its own automatically results in academic success. Retention is inadequate if it is not accompanied by understanding, connections and application of mathematical concepts (Maffei & Marriotti, 2007).

Emphasis on retention of prior mathematical concepts seems to be going against Dale and Hyslop's (2010) assertions that "education is a democratic learning experience whereas banking education, indoctrination, and training undercut the rational agency of the learner" (p. 30). It is pertinent to note, however, is that Dale and Hyslop are not criticising the function of retention in mathematics education per se, but rather the deficient methodology through which the goal is pursued. As has been already highlighted, certain subjects such as mathematics, require a certain amount of recall of prior knowledge to which further learning experiences are connected. Learning gaps arise where such connections are absent. By acknowledging that learning results in a permanent change, Dale and Hyslop (2010, p. 82) viewed retention as a goal, rather than a means to that goal. This of course is just partially accurate since concepts 'grow' and cannot be regarded as 'permanent'. Change that results from learning occurs gradually, and so during a student's life there will be a series of micro phases of 'permanence' that alters after each new learning experience. The permanence, therefore, should relate to a transitory and not a perpetual state.

Granted, it is not every mathematical topic that is hierarchical and sequential. Depending on their complexity, certain topics, for example in geometry, can be taught successfully without the need to draw from concepts learnt previously. Outliers that do not fit into this pattern are acknowledged. What is sufficient at this point, however, is that subsequent learning is enhanced and accelerated (as indicated by the phrase 'block of blocks') when learners' prior knowledge is connected to their new learning experiences.

A study by Neisser (1982) on a memorist named Nancy showed that besides decay and interference, memory can be poor for uninteresting subjects because the brain selects what it deems important. The research further confirmed that what goes into the brain is hardly what is retrieved, because sometimes important information is thrown away together with unwanted items. Memory loss happens through proactive and retroactive interference or natural decay. This loss is due to the brain function that allows it to pick and choose as well as alter the information it receives (De Bono, 1969).

As has been explained before, the concept of retention does not limit itself to a simplistic process of memorisation that manifests itself in the ability to parrot and rehearse mathematical facts. Rather, as has already been mentioned, it allows and emerges from a process of understanding and insightful mathematics learning. Maffei and Marriotti's (2007) statement that "… memorisation, cannot be separated from understanding …" (p. 1461) supported this. Any discussion on teaching for retention in the absence of understanding, would be insufficient. The major difference between retention and the traditional learning by rote is in the relative elasticity, type and depth of encoding and the absence of understanding and connections between concepts that usually characterises the latter.

Retention is one of the three components of the memory cycle that affects and is affected by, supports and is supported by, builds and is built by, amplifies and is amplified by conceptual understanding, retention itself and application. Indeed, retention affects and is affected by understanding, application and retention! As already indicated, a closer analysis of the three goals of learning confirms that not only are they the transient goals or destinations of (mathematical) learning, but frequently the very means to those goals as well. If mathematics teachers realise this, conceptual development in children will accelerate to exponential levels and learning would not stop.

Perkins (2001) argued that learning takes place when the cognitive system acquires and keeps information for further use and that if the process is flawed, learning may not take place and learners will not have resources to use to extend understanding or engage in thinking procedures that demand application and merging of different ideas to solve complex problems. This argument by Perkins formed the rationale for analysing documents that provide descriptors of how learners acquire, keep and use concepts in the classroom. The view that concepts learnt ought to be used is supported by achievement oriented learning that focuses on the availability of retained subject domain concepts to solve subject domain problems. For this to happen, subject domain concepts should be retrievable from the long-term declarative memory, bearing in mind that constant retrieval strengthens memory pathways. Retrieval of stored concepts is largely dependent on the process of encoding, which is best achieved through the use of ICTs (Ferriman, 2014)

2.2.2 The Function of Retention in Mathematics

The function of retention in mathematics is both suggested and given clarity by Lev Vygotsky (1978) who used the term ZPD to refer to “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers” (p. 86). This process, similar to scaffolding, allows learners to be guided “… from what is presently known (and stored) to what is to be known” (Karagiorgi & Symeou, 2005, p. 20), permitting learners to concentrate on and complete only those elements that are within their range of competence (Wood, Bruner & Ross, 1976). Scaffolding does not happen in a vacuum. The basis of this process is the working memory that draws from the declarative and procedural long-term memory. Learners should attach new learning experiences to their prior mathematical skills and internalised knowledge for the process to be successful. Without that and a supportive pedagogical context, ICTs only serve as a new medium and platform for the perpetuation of traditional pedagogies, with little or no positive impact on the retention of mathematical concepts.

Perkins (1999) listed the three distinct roles of active learner, social learner and creative learner as common features of a constructivist learning space. It is "… active engagement in learning (that) may lead to better retention, understanding and active use of knowledge" (p. 8). This kind of learning is more than just a mastering of putative, stable, well defined or existing knowledge. Karagiorgi and Symeou (2005) and Kanuka and Anderson (1999) argued for an awareness of learners' current understanding that allows them to create new knowledge. Again, the very idea of expansive learning implies the existence of a retained concept or knowledge that requires extension and transformation. The cycle goes on with the next step using a transformed concept as a new retained concept. Therefore, this research claims that the effective use of retained prior knowledge accelerates learning to almost exponential levels. This probably explains that learners who demonstrate a good understanding of foundational mathematics continue to excel later in their school life, because while other learners are laying a conceptual block at a time, they will be laying a block of blocks each time.

It should be noted that Engestrom's (1987) reference of collective generation (community practice) would be inadequate if it excluded a rich pedagogical setting and ICT tools that encourage multiple perspectives in learning (Kafai & Resnikno in Karagiorgi & Symeou, 2005). Engestrom (2010) also stated that ascension "… from the abstract to the concrete is achieved through specific epistemic or learning actions that are better mediated by today's cultural tools (ICT tools)". This process refers to the movement of retained concepts from their simplex to complex transformed forms, leading to a situation where retained concepts support the retention of even more concepts. He further said "together, these actions form an expansive cycle or spiral..." (p. 6), leading to the construction and resolution of "successfully evolving contradictions" (p. 6). As has already been suggested, retention supports further exponential retention levels. This advanced form of learning has intermediary processes within the learning space that require facilitation by expert teachers using ICT tools within an enabling pedagogical setting.

The view of expansive theory contradictions in the current research is not limited to change at macro levels only as is usually the view, but is also applicable to a variety of novel micro situations. For example, contradictions to a learner's retained knowledge leads to an emergence of new knowledge, bearing in mind that contradictions do not necessarily have to be oppositional. This change is what pushes them to ascend or grow from the retained concept to a new conceptual understanding. Learning happens when the learner accommodates retained concepts to their new understanding. Hamat and Embi (2010, p. 238) referred to existing past constructions as mental frameworks. The authors argued from a Piagetian framework and concluded that familiar knowledge is assimilated into (existing) mental frameworks while accommodation is for unfamiliar information accommodated into existing (existing) mental frameworks. Reflective learning (higher order) happens when learners seek to "resolve cognitive conflicts, or expansive contradictions, by improving on the prior framework" (Hamat & Embi p. 238). Again, even from a cognitivist perspective, the functional existence of existing frameworks or retained concepts as a basis for further mathematical understanding cannot, therefore, be underrated. The store of the old view, the existing mental frameworks or existing concepts and skills are constituent parts of what is broadly referred to as retained concepts in this research. The next learning episode connects to those concepts to develop a new set of knowledge, and so on.

As explained above, retained concepts serve a dual function of being both the conceptual resources that are both requisite raw materials to be used for the formation of new conceptual understanding and boundaries, and of being, in their 'resolved' or 'permanent' (new ZAD) states, transient products of an ongoing learning endeavour (what I refer to as the 'means' and 'transient goals' of learning) (Engestrom, 2010). Expansive learning uses internalised(retained) concepts to form new expanded concepts, and these transient products and internalised concepts also form part of the internalised conceptual resources (Engestrom, 2010). Criticism to my reference to expansive learning is based on the fact that the theory is macro focussed and is not the ideal stand-alone constructivist theory to explain the formation and use of retention within a 30 minute or one-hour mathematics lesson, for example. In this research, however, the theory's relevance is in its principles that address object transformation (two states) and mediation that are applicable even at micro levels, as shown by the following observations:

1. Its reference to movement from action to activity that result in the theory being referred to as an activity-producing activity is synonymous to Perkins's goal of application. In this research I argue that the application (of a retained concept) is a necessary step towards an incremental conceptual development and formation of a new and firm ZPD. In simpler terms, the application of concepts learnt in class support further retention. Literature seems to suggest that not only are ICTs well placed to support direct retention of concepts, but they also afford the context through which such retained concepts can be applied, and in the same process, support even further retention.
2. The distance between the everyday actions (known or retained concepts in the firm zone) and "the historically new form activity …" (Engestrom, 1987, p. 4) is basically the movement and application of retained concepts within the ZPD to form new concepts. Seen this way, the goal of retention is not a fixed (or permanent) goal. It is a transitioning goal that is in constant motion. For as long as one still learns, connects and uses knowledge, what they retain grows and varies every moment of the hour, day, year and lifetime.
3. To strengthen the above argument, the theory again mentions the transitions from the abstract to concrete or from "… the smallest and simplest genetically primary unit of the whole functionally interconnected system …" (Engestrom, 2010, p. 5) to a higher level of learning with concepts that are understood and retained, potentiating further mathematics learning. Concepts learnt in class are elementary parts of a larger context and teachers and learners must demonstrate an understanding of this. Application of knowledge to real life problems is one way of providing that context with the question now being directed at whether ICT tools have the potential to do that.
4. The dual role of the cognitive indicators of retention in both the creation and establishment of new zones of actual achievement (what the learner can do unassisted) needs further exploration. The learner can traverse their new cognitive zone with the help of retained skills. In the very same process, they re-establish new ZAD and ZPD boundaries, and if the process is successfully done, they grow their scope of understanding exponentially over time. Forgetfulness as a result of decay and

interference is the greatest threat to the growth of the ZPD. A good ICT tool should possess features that slow down, or if possible, prevent knowledge shrinkage so that learners retain as much as possible of the skills and concepts learnt in previous lessons and concepts. As has been seen in literature, forgetfulness sometimes serves a functional role and is, therefore, sometimes essential.

It is because of this dual nature of retention that this research argues that retained concepts establish the old and are the basis for the formation of new knowledge in the ZPD. This duality is confirmed by the concept of preservation and transmission and that retention is both an extension and reception process. An extension because the retained items form a basis for application in problem solving and further movement along the ZPD spiral. A reception process because retained concepts act as the building blocks of new conceptual understanding and even further retention. In between, conducive pedagogical practices provide a connection between the reception and extension process.

The transmission mentioned above, as has already been mentioned, is not just that of the original concept. Rather, it is the transmission of a growing and amplified concept, previously explained as the block of blocks growth in the retention metaphor. There is a construction of a new object (knowledge) and concept of collective activity as well as the implementation of the new object in practice during the application process. In other studies, retained items and their higher order conceptual applications are regarded as actions and activity, respectively, or as abstractions and concrete teaching formats, respectively (Carpay, 1996, p. 5). Davydov' s (in Hershkowitz, Schwarz & Dreyfus, 2001) reference to initial abstractions or the germ cell's (the retained concept) back and forth movement in the ZPD and their gradual re/construction or development is once again a presupposition of the existence of abstractions that allow future understanding and application to successfully occur (Carpay, 1996). An understood concept, that is retained and applied results in the growth and retention of that concept, and because learning results in the incremental growth of knowledge, the back and forth movement of the concept in the learning space is a movement of a growing and not of an unalterable concept.

Because of the abstract nature of the concept of retention, visible and externally observable practices have been identified from literature as practices that enhance retention. These practices, hereafter to be referred to as indicators of retention, constitute what can be likened to "Vygotskian conceptions of how visible and externally provided guidance can be internalised to become self-guidance …" (Salomon & Perkins, 1996, p. 5). ICT affordances and pedagogical practices were evaluated to a large extent on how they promote each of the indicators. Application, which also enhances retention and can therefore be regarded as an indicator of retention, has been excluded to allow for an exclusive and clearer focus on the goal of retention.

The indicators listed below will be used as the basis upon which documents and researches on all categories will be evaluated to determine their possible impact on retention.

2.2.3 Indicators of Retention

Indicators of retention confirm that learning has to do with registering and storing information and that storage and retrieval of information cannot be regarded as totally separate functions (Baddeley, 1990). This is supported by the levels of processing approach to memory that observes a "… relationship between how information is encoded and how well that information will be remembered" (Magill, 1993). The indicators of retention therefore seek to establish how well mathematical concepts are encoded, understood and stored in order for them to be used to solve problems or extend knowledge to verify how information is encoded and stored during the learning episode. It is as a result of this assertion that the indicators outlined below range from the initial cognitive process of encoding to the use of concepts during application and in extending knowledge, and is why documents that are suggestive of these processes such as lesson plans, exercise books and so on were evaluated in this research. One might ask, why is the researcher describing this category in detail? The answer is that the sub-elements of retention as a category overarch every aspect of the recommended new pedagogical framework.

De Bono (1969) gave an analogy of a dog's muddy paws to explain the importance of retention. If such a dog were to walk across a room, it would leave traces and a memory of its passage. The listed indicators have the potential to leave 'muddy paws' that create deep learning imprints and in the process make mathematical concepts more memorable. While the choice of indicators is subjective and therefore subject to contestation, they appear in literature as being sufficient to signal the retention of concepts. It is these indicators that ideal pedagogical contexts should seek to promote and enhance. Indicators and their emergent sub-elements are summarised and reviewed based on the findings from the various sources of literature and data used in this research.

2.2.3.1 Perceived Utility

The retention of mathematical concepts is enhanced by it perceived utility or the likelihood of usefulness of those concepts (Abadzi, 2006). Is it possible that ICTs strengthen the link between the learners' daily existence and the mathematics they learn in class? Learners pay attention and store mathematical concepts because they are applied to everyday scenarios and they consider them important. Good practices, tools and mathematics should link learning to these everyday contexts. Neisser (1982) used the term 'consequentiality' to refer to learning that impacts directly or indirectly on one's life or everyday contexts. The manipulative potential of ICTs to make mathematics learning relevant was confirmed by Vernon (1970) who said perception can be manipulated (facilitated, or inhibited) "towards a particular feature of the environment, in accordance with knowledge, experiences, interests and motives of particular persons" (p. 228–237), allowing the tools to afford virtual platforms that allow learners to interact with concepts within simulated and controlled environments. A good learning platform should provide opportunities for learners to practically use the skills and concepts learnt in mathematics classes.

2.2.3.2 Connectedness

Salomon & Perkins called connections in learning and teaching a "networking pedagogy" (1996, p. 17). This happens when technologies momentarily align two concepts (narratives) usually kept as separate entities to create a unified whole (Neisser, 1982). When this happens, the concept is aligned with our lives to create a flash bulb effect. We remember the details of mathematics lessons that are related to other lessons, subjects or our own experiences, creating a link between our own histories and History (Neisser, 1982). Connections are referred to by authorities such as Anderson and Bower (1973) as associations. It is important to establish if and how pedagogical practices and ICTs promote associations within mathematical concepts and with other subjects, a concept commonly known as integration, to create a flash bulb effect.

In his study on ACT*, Anderson (1995) said, "Spread activation proposes that activation travels along a network of connections and that so once cued, a subject may have multiple responses based on the connections among bits of information in memory" (p. 1). The development of successful long-term mathematical memory and retrieval is determined by the successful encoding of concepts in the short-term memory. Short-term memory success is dependent on attention, which relies heavily on interest in the mathematics lesson. Anderson and Bower (1973) outlined the following four features of associative theories: Ideas; sense data; memory nodes, or similar mental elements that are associated together in order to make the association; and connections. Ideas can be decomposed into a single idea making the association reductionist, strong and efficient. In other words, a single mathematical connection allows learners to retrieve many other related concepts.

The association includes internal processes and identifies the basic components of the mind with sensory experience making them sensationalistic. "If events are not as important as anticipated, they get deleted" (Neisser, 1982, p. 88). One of the things that this research asked was whether concrete objects are better than computer simulations in making experiences sensationalistic. An event such as a mathematical concept should have descriptors such as where, what happened, who, when and why etc., which can all be used as flexible cues to "reinstate the target memory" (p. 90) or the concept learnt. The more varied experiences a learner has with a concept, the easier it becomes for them to retain it.

The study on lesson plans and other documents again tried to verify whether mathematics teachers are teaching mathematics lessons in context. Multiple connections enhance retention and the "… more numerous and specific the discrete cues become, the more precise memories should be specified", (Neisser, 1982, p. 91, 337–339). The application of mathematical concepts allows for accompanying contexts in which these variations are used, which allow people to store in memory more than just information they are trying to remember. Along with information stored, context characteristics become important cues for retrieving the stored information on a retention test. It is important to establish whether and how the four research categories enhance connections between mathematical concepts to other concepts, subjects and contexts in order to create multiple connections that enhance retention.

Since retention happens at micro levels as well, as has been established in literature, connections should be present in every lesson, between lessons and in the whole learning life of the learner if the retention of concepts and consequently performance in mathematics are to improve exponentially in South Africa.

2.2.3.3 Elaboration

Elaboration (Perkins, 1991), or Neisser's (1982) interactional content, includes Tulving's encoding specificity principle that attempts to relate conditions of learning to the conditions of optimal retrieval. But a question come to mind: If ICTs are used for learning, should tests and assessments also be conducted using ICTs? The law of levels of processing argues that the more deeply and elaborately a mathematics item is processed, the greater the probability of subsequent recall (Craik & Lockhart, 1972). According to Jones et al. (1977, in Kanuka & Anderson, 1999), elaboration involves creating meaningful and challenging experiences that involve planning, development over time, presentations and debriefings of what has been learnt. With the current pacing and sequencing of mathematics teaching, it is likely that unless this process is factored into the syllabus, debriefings and presentations on what has been learnt will simply be brushed aside while teachers teach for tests and assessments.

During deep rehearsal, learners have an opportunity to act on mathematical concepts from different perspectives, and it would be unwise to suggest that a single tool or approach of teaching is panacea. ICTs, for example, allow learners to do a variety of activities on the same concept. As Piaget (in Ripple & Rockcastle, 1964) said:

> Knowledge is not a copy of reality. To know an object, (or a mathematical concept) is not simply to look at it and make a mental copy or image of it, but to act on it. To know is to modify, to transform the object, and to understand the object of its transformation. (p. 8)

Elaboration allows the learner to look at the mathematical concept from many different angles and multiple representations of reality (Cey, 2001, in Karagiorgi & Symeou, 2005). Perkins (1999) called these alternative perspectives. Magambo (2007) argued that computers are ideally suited "… by virtue of the flexibility they can provide, for fostering cognitive flexibility" (p. 25), which comes about through the learners being presented with concepts in different formats.

2.2.3.4 Attention

According to Neisser (1982), people tend to remember things that interest them and memories of uninteresting subjects are poor. Attention is enhanced by factors that include content dependant multimodality effect, which ICT generally afford. Platforms such as Mathletics allow learners to hear instructions, see pictorial visuals and increase attention through competitions.

If interest enhances retention, in this day and age it would be folly for educational systems to ignore elements of gamification that offer that affordance. Baddeley (1992) argued that spoken words enhance relevance of discourse and that auditory presentations are better than visual. He also argued that chunking or grouping of mathematical items enhances retention. According to Vernon (1970, p. 103), "the main factor involved in the decrease of vigilance (attention) in tasks is a decline of arousal, which is caused by habituation to a relatively unchanging situation which has little natural interest" (p. 103). Vernon also explained that homogenous stimulation over a period of time leads to boredom and lowered attention. What is the potential of ICTs to mitigate habituation that affects retention?

Baddeley (1992) argued that human memory is acquired through senses, and hence, mathematical lessons that involve a variety of senses are likely to be more memorable. Perkins, (1991) used the term 'active engagement' to refer to the process whereby the learner acts on the learning experience through a variety of ways that ultimately positively impacts retention.

2.2.3.5 Rehearsal

Rehearsal (Neisser, 1982), or practice of mathematical concepts as explained by Abadzi (2006), is essential and was defined by Magill (1993, p. 226) as a "… process that enables the individual to transfer information (mathematical concepts) from the working memory to the long term memory". Perkins, (1999, p. 10) pointed out that "… the best way to remember a body of information is to organise it actively, looking for internal patterns and relating it to what you already know". The role of connections in learning cannot, therefore, be overemphasised. He argued that although simple repetition or surface rehearsal is helpful, it is insufficient. Various researches, including one by ACT*, which is a cognitive theory dealing primarily with memory structures, has shown that reaction time for fact retrieval increases as a function of increased frequency. The research concluded that two factors influenced levels of activation, which in turn influenced recall: How recently the person has accessed memory, and how much they have practised or rehearsed the concepts (Anderson, 2010). Would ICT s offer better opportunities for such practice? Spiro, Feltovich, Jacobson and Coulson, (1991) referred to an image that Wittgenstein used and compared it to a landscape: "In order to acquaint oneself with this landscape, one has to traverse it many times in different directions, one has to criss-cross it"

(Spiro in Magambo, 2007, p. 25). Spiro's assertion summarily puts pay to the notion that ICT alone should form the basis of all learning.

Frequent rehearsal of mathematical concepts is said to also enhance numerical accuracy (Neisser, 1982). Maintenance rehearsal is sometimes referred to as Type 1 rehearsal and involves repeating the kind of analysis that has already been carried out. This type of rehearsal has already been shown to be less effective (Craik & Lockhart, 1972). Elaborative rehearsal on the other hand involves a deeper, meaningful and analysis of rehearsal that caters for the growth of the concept (Craik & Lockhart, 1972). Research has shown that trace decay, when forgetting occurs with the passing of time, can be mitigated by consistent and spaced out rehearsal of mathematical concepts (Magill, 1993). Magill (1993) concluded that what happens between mathematics lessons (during the retention interval), affects recall. Over practice or over learning beyond what is needed to "… lessens forgetfulness through retroactive interference" (p. 236). Time and activity have been identified as having an influence on forgetting (Magill, 1993), and it would be insightful to see how practice reverses acceleration of time and activity mediated forgetfulness of mathematical concepts. Again, all these practices require careful pedagogical planning on the part of the teacher.

2.3 **ICT Affordances**

This section provides further clarity on and addresses the third research objective, 'To establish how the use of ICTs contributes to retention of mathematical concepts', and the sub-question 'Which ICT affordances enhance retention of mathematical concepts?'

It must be noted at this point that there are many overlaps between the categories addressed by the documents used for data collection in this research.

Claims have been made that ICTs have a greater likelihood of hitting on a variety of learning styles, which in turn positively impacts on retention (Ferriman, 2013). To test this and other similar claims, retention was broken up into indicators of retention and then further into their sub-elements, which were then matched with ICT affordances as they relate to the topic during data collection and analysis of selected categories.

While ICT is simply a pragmatic term for various technological devices, the affordances and commercial value of these devices are different and unique, and hence, their actual contribution to enhancing retention would most likely be varied. There are many groups of ICT tools that include situating, constructive or communicative tools as well as categories based on how the tools are used. Situating tools, for instance, can be used to "improve in organisation and memory …" (Hogle in Lim & Tay, 2003).

Although claims have been made that ICT affordances enhance retention of concepts (Ferriman, 2014), my observation is that not all of them do this as a result of the already mentioned differences. Because of practical considerations, only ICT affordances related to the iPad, tablet, calculator, video, and to a lesser extent, IWB and two mathematics programmes were analysed, because these are the tools commonly used in schools to mediate learning. And because this is a conceptual study, it was within my purview to critically evaluate even those affordances that with creative use potentially possess a significant influence on retention.

The Merriam-Webster dictionary (2017) defined affordances as "the qualities or properties of an object that define its possible uses or make clear how it can or should be used". The research therefore sought to establish not only how ICT tools have been used in the past, but also their potential to enhance retention. For example, the built-in interactive, manipulative potential and informative capabilities of certain ICT tools suggest they have a superior advantage in supporting the retention of concepts. That efficacy depends on a variety of factors, including the way the tools are used during learning. The sum of these factors are herein referred to as the pedagogical context and include the four low-level categories studied in the literature and evaluated in the data collection and analysis section, and other emergent categories that emanate from the study of the core categories.

The affordances of most current ICT tools are far beyond the scope of what Vygotsky envisaged when he initially referred to cultural tools (Vygotsky, 1978). To a great extent, platforms such as YouTube, Wiki, Mathletics and Cami, among others, have assumed the role of a 'more capable other' since they possess efficient and reliable search and instructional capabilities, with a greater potential to enhance learning than ever before.

It is important to provide a distinction between the actual and perceived categories of affordances with particular emphasis on the tool's construction and ease of use. Factors such as the design of a tool and implications on how it is used, referred to as its perceptible affordance, may have an impact on whether the tool will successfully enhance retention of concepts or not.

In certain instances, however, it has been shown that ICT affordances are unlimited since their use is determined by the users' creativity and inference. The idea behind this is that with innovative use, any, or at least most ICT tools, can be creatively used to enhance the retention of mathematical concepts. This type of affordance is referred to as the tool's hidden affordance. Kennewell (2006) supported the above assertion by arguing that technological tools will not act independently of pedagogical settings in which they are used and that an evaluation of the impact of ICT on teaching and learning requires an "… accompanying detailed analysis of the complete pedagogical setting" (p. 102). The role of the teacher in ICT mediated learning must also be described since it is one of the factors of the complete pedagogical context that impacts ICT tool use. Gibson (in McGrenere & Ho, 2002) argued that affordances are both independent of an actor and subjective, and that what the actor does with the object is what defines the object's affordance.

McGrenere and Ho (2000, p. 2) referred to what they termed "the actor-environmental mutuality" between the actor and his environment. In another instance, they referred to the actor and his environment as an "inseparable pair", with tools having a bearing on whether they can be used for certain purposes or not. Gaver (1991) was of the opinion that an understanding of affordances should show a link between simple and complex affordances together with their consequent necessarily sequential revelation. What Gaver (1991) here suggested is that it is the user's exploration that actually leads to this 'revelation' of the tool's affordances. Studies by Hamat and Embi (2010, p. 243) partly supported my view that "… although computers are epistemological tools often associated with cognitivism and behaviourism, it is in actual fact their use that makes them constructivist in nature". It is also true that the design of certain technologies provides them with inherent advantages for facilitating the category of retention over others.

Karpov (2012) explained how ICT tools are used to promote retention of 'cognitive tools' that are then applied to further enhance learning. Baddeley (1992) also argued that human memory is acquired through senses and that generally ICT tools are better placed as intermediaries of learning and recalled items. ICT tools are not only ideally placed to support retention, but as constructivist tools they also mediate the movement of retained concepts from abstraction to concrete concepts through a process akin to application, which in turn promotes further retention in the process, creating short-term, long-term, and individual and as well as broad ZPDs

(Newman & Holzman, 1995). This is the real reason why this research is located in a micro and macro learning space (Kennewell, 2006), alternatively referred to as the ZAD and the ZPD. Newman and Holzman, (1995)'s description of the ZPD is the clearest way of tracing the movement of retained concepts from the micro level of a single lesson to a macro learning space during lifelong learning. In between, we find numerous ZPDs and enabling micro and macro pedagogical settings, including the role of the teacher in guiding ICT mediated learning.

One of the most important affordances of ICT tools, that of transforming education, is based on their potential to shift control of learning to the learner (November, 2010). This marks a shift from the era of passive mathematical learning to active learning, as clearly explained by both the social and cognitive theories of learning. Children learn better when they actively take part in a lesson, as the adage goes: Tell me and I forget; Teach me and I may remember; But involve me and I will understand'. The importance of the learner and the transformative power of ICT has led to personalised learning, which both empowers and liberates the learner, resulting in personalised learning (Keane & Keane, 2013). In spite of so much potential, the authors, however, agreed that it is in fact what the teacher does with the ICT tools, rather than the perceived affordances, that determine whether ICT tools are able to support the retention of concepts.

Haddad (1999) listed motivation, simulated and collaborative learning environments, and the provision of authentic situations (what I would like to term learning contexts) as some of the inherent advantages of using ICTs. Again, it should be established whether these affordances have a link with the indicators of retention mentioned herein. Gaver's (1991) argument that "learning is seen as a matter of attention rather than interface" (p. 82) supports Abadzi's neuropsychological view of encoding and perception. The role of a good interface such as technologies being that of guiding "… attention via well designed group of sequential and nested affordances" (p. 82), resulting in increased retention of concepts. The importance of attention was explained in greater detail in the literature on indicators retention.

Hammond et al. (2001) argued that ICT affordances and constraints serve the dual function of potentiating and restricting the use of these technologies with implications on subsequent pedagogical imperatives associated with their use. Supporting this assertion is Kennewell (2006) who described affordances and constraints as "… the conditions and relationships amongst attributes which provide structure and guidance for the course of action" (p. 106). He further argued that constraints are complementary to affordances as they allow activity to take place. It is important to note that designers of technologies have been trying to make the new inventions more user friendly, especially for non-specialist users, with hardware and learning applications such as Mathletics being customised to meet the user's specific needs and requirements.

In conclusion, while the review of literature might appear to have been presented in seemingly 'detached silos' (which is also the structure adopted in the data collection and analysis), the format is deliberate and meant to provide a deeper understanding of each of the four selected categories before they are systematised. Much depth has been provided for the core category of retention to analyse how its elements fit into the other categories that inform this research. The pedagogy category features in the literature of all the other three categories, and hence, has not been presented separately in the review of literature.

Theoretically, the nature of positivist mathematics has been established to be objective, connected, sequential and hierarchical, which justifies the need for the retention of concepts. Retention is a cognitive construct that is best achieved through the mediation of ICT tools (Ferriman, 2014). Retention itself has been broken down into indicators and sub-elements upon which the effectiveness of ICT tools' potential to hit as many indicators of retention as possible was based. The evaluation of different documents was also based on how they relate to practices that promote retention.

It has been argued that the use of ICT without an enabling pedagogical context does not necessarily enhance retention. While it is acknowledged that the pedagogical setting is a multivariate system that makes it impossible for learning to happen in a linear and always predictable form, it was within the scope of this study to recommend a broad but practicable pedagogical framework that leverages the potential of ICT to enhance the retention of mathematical concepts.

2.4 **Conceptual Framework**

This is a pragmatic conceptual study that sought to establish the potential of ICT tools to solve an existing problem of learners failing to retain mathematical concepts. The major concepts of this research lie on two different theoretical planes, cognitivism and constructivism. The research's view, therefore, is that teachers should not be blinkered by the knowledge of pedagogical exclusivity of a single framework that ignores different viewpoints. By so doing, there is a risk of losing out on other beneficial pedagogical approaches that straddle philosophical lines. This is especially true for ICT mediated learning where behaviourist views, the Technical, Pedagogical and Content knowledge (TPACK) model, expansive learning, prevailing cognitive and social theoretical frameworks can all be ‘borrowed’ to explain how ICTs are incorporated to leverage retention of concepts.

The conceptual framework used in this research is based on Perkins’s very simple but essential three goals of learning, which are understanding, retention and application, illustrated in Figure 2-1. The three goals suggest that teaching for recall or understanding alone leads to the achievement of only one of the possible three learning goals, and is therefore ineffective. The acquired concepts need to be retained so that they will act as (evolving) raw materials for the next lesson as well as being used as resources necessary for knowledge transfer, and in the process, enhancing further retention.

ICTs are claimed to have a long-term cognitive and affective impact on students (Dori, Hult, Breslow & Belcher, 2007) and would therefore be the best medium of teaching concepts for retention. The potential for the cognitive and affective domains that enhance retention were studied through an analysis of ICT tools as well as practices that leverage the potential of these tools to enhance the retention of concepts.

Retained concepts, also referred to as prior knowledge, foundational concepts or conceptual resources, are the existing knowledge, skills and attitudes that each learner brings into the new lesson. The term retention itself has a variety of meanings and has been operationalised in the research to include practices that promote perceived utility of concepts, connectedness, elaboration, attention, rehearsal and their sub-elements, which have been used as the basis upon which all documents will be evaluated during data collection and analysis.

These retained concepts have a function of being the new ZAD for the new lesson and are transferred or applied during problem solving. The process goes on, not always necessarily in a linear form, resulting in learners forming more advanced and new ZPDs each time. It is sometimes possible to initiate learning from any of the three goals, such as in the case of lesson provocations. Irrespective of how or where the lesson starts, learners still require existing conceptual resources to extend learning efficiently. Learners who lack retained skills find it hard to move onto higher levels of abstraction. This view has implications on the structure of the lesson plan; the sequencing of mathematics topics; the allocation of teachers, especially in the foundational grades; assessments and tests; the selection of learning tools; as well as the other accompanying mathematical pedagogical practices.

It is implied in the formation of higher ZPDs that this learning space should not be regarded as a single, fixated space, but rather as a multi, continuously transitory spiral space with numerous levels of abstraction. This is what Karagiorgi and Symeou, (2005, p. 18) referred to as the "many levels of abstractions for knowledge construction". The ZPD grows, sometimes exponentially, but has a rather normal tendency to shrink because of inevitable interference and decay (a process commonly referred to as forgetting); hence, the need to establish how ICT tools mitigate this.

Focus on ICTs as a special type of tool that impacts on categories of cognition such as memory finds support in Newman and Holzman (1995) statement that "… tools, affect their users". Deriving from this statement, I concluded that superior tools should have a superior impact on their users. In the context of this research, the selection of tools used for mathematical learning in specific pedagogical contexts has an effect on the retention levels of mathematical concepts. This idea is further explained by Shweder and Sullivan (in Altarriba, 1993, p. vii):

> … psychology in a technological context forms the basis of comparative study of the way culture and psyche make each other up … that performance differences among human populations may arise from the partial translatability or limited commensurability of stimulus situations and materials. (p. 488–489)

It is the quality of stimulus and learning tools that determine mathematics achievement! If ICTs actually have a positive impact on cognition as Newman and Holzman (1995) suggested, there is a real possibility for many already ICT resourced South African schools to improve the retention of mathematical concepts, and consequently, performance in mathematics in a better way than ever before, provided the material (mathematics taught) is presented correctly. Granted, possible challenges such as other pedagogical issues and inadequate professional development exist (Flanagan & Jacobsen, 2003; Kennewell, 2006). This study provided recommendations on how these challenges may be overcome.

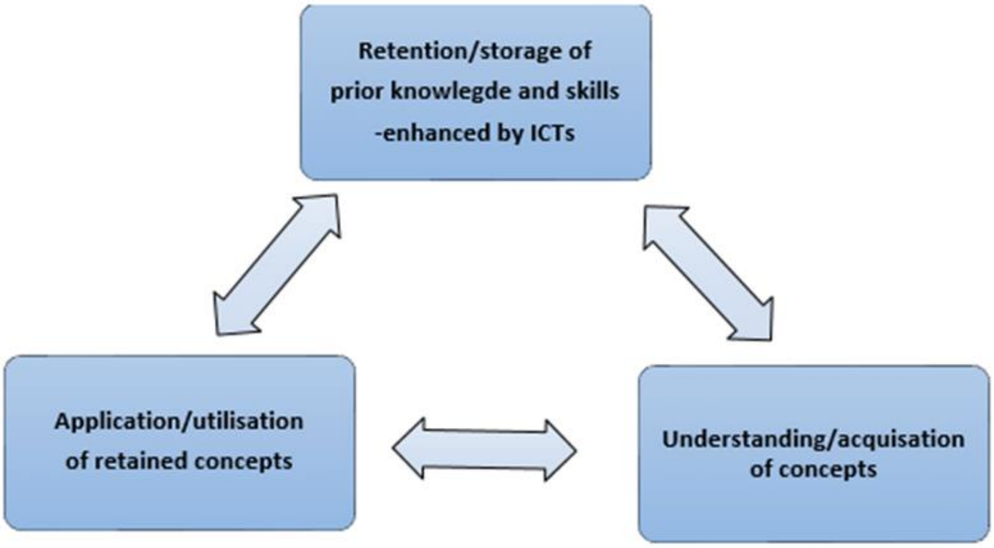

Figure 2-2 The intertwined and symbiotic relationship between Perkins's (1991) goals retention, understanding and application. Retention is shown here being impacted and impacting on understanding and application.

Although Perkins (1991) listed retention as one of the three learning goals, the goals are actually intertwined, and they affect and are affected by the others as illustrated in Figure 2.2.

Mishra and Koehler (2006) used the TPACK model to explain how the teacher's pedagogy, lesson content and integration of ICT technology transform retained concepts in the ZAD to higher levels of thinking. The authors did not, however, explain how exactly this happens. The research studied the role of the teacher and technologies in orchestrating affordances and constraints in that space (King & Chu, 2012), thus allowing learners to traverse between retained mathematical concepts and what can be achieved within a given learning space.

Although the literature review provided distinct information on the three, the last category on pedagogical setting pervades the first three categories and is explained contextually within each of them. The rationale for my approach was explained in Chapter 3.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 **Philosophical Foundation**

This conceptual qualitative research used the grounded theory approach to study the selected four low-level categories. Grounded theory is building a theory based on observations by the theorist summarising data into categories that are then tested for coherence; these are then linked and evolved into the theory (Glaser & Strauss, 1967).

The studied four categories together with their emergent higher level categories revealed in total the type of stimulus (nature of mathematics, in this research) and materials (ICT tools) that likely form the basis of differentiated performance in mathematics among learners (Shweder & Sullivan in Altarriba, 1993). The type of stimulus includes, among other things, the nature of the mathematics being taught and the pedagogical practices that have an impact on retention. These categories are reflected in the four research objectives and sub-questions address the main research question and the research topic.

The grounded theory methodology used in this research allowed the study to "… open up a space for the development of new, contextualised theories" (Willig, 2013. In this research, the final product was a pedagogical framework guiding how ICT can be used to enhance retention of mathematical concepts. The basis of the grounded theory is pragmatism, or the practical effects of a conception, as has been the focus in this study. The current practical problem facing South Africa are the worryingly low achievement levels in mathematics. Because of the nature of this study and it being arguably pioneering research on the topic, a lot of detail has been included, not only on ICT affordances but also on the other three categories. Indicators of retention have been broken down into sub-elements to add more detail to the descriptors of this category.

Goldkuhl (2012) argued that although alternatives exist, qualitative research is often associated with research that allows the researcher to include their perspectives that emerge from an analysis of contextual factors, excluding the analysis of researchers, that led to certain findings. Such inferences from literature are important, especially for conceptual studies, because "the world is not conceived as a fixed constitution of objects" (Orlikowski & Baroud, 1991, p. 13). As a result, a lot of reinterpretation and inferences have been drawn in this research based on available data from the identified sources. One of the features of this qualitative grounded research is that although it starts with skeletal categories in the form of indicators of retention, and the three sub-categories of the nature of mathematics, these are absent in the other two categories. The skeletal measures themselves were subjected to refinement during an analysis of research papers and documents.

The grounded theory, which is an alternative qualitative data analysis, is an iterative and reflective process (Glaser & Strauss, 1967) that required me to jot down and revise notes during the process of reading and interpreting the data. The nature of data analysis shifted the focus of and refocused the research many times, which led to a product that was not initially envisaged.

I studied the identified low-level categories from primary and secondary sources through the lenses of the indicators of retention and its related sub-categories, after which higher level or more complex categories emerged. These were studied and refined until a stage of theoretical saturation was reached, meaning no new variations of the developed categories emerged.

Usually categories emerge during the data collection, but in this research, they initially emerged and were identified from the literature and were used as interpretative lenses during data collection and analysis. During data collection then, higher level or sub-categories emerged that I interacted with till a stage of relative saturation. The term relative has been used because the limitations of time and space would not allow me to collect further data sources.

3.2 **Research Design**

Research design is a strategic framework for action that serves as a bridge between research questions and the execution, or implementation of the research strategy (Durrheim, 2004, p. 29). Saunders, Lewis and Thornhill (2012) define it as a general plan used to address the research question.

A qualitative exploratory design was used because it allowed the research to gain insights into an area that are still considered hazy. Qualitative studies allow the study of things in their natural settings allowing the researcher to attempt to make sense of or interpret phenomena (Newman &Benz, 1998). The approach allowed the researcher to use small samples of many sources of information that were selected purposively in order to observe patterns that emerge from a variety of angles. The iterative nature of the research required numerous stages of reinterpretation, refocussing and reflective processes, all of which required flexibility that could only be allowed by an exploratory research using grounded theory approach (Glaser & Strauss, 1967). Exploratory research allows for use of secondary data that was used to gain a deeper understanding of the numerous but interconnected loose ends of categories in this research. Of course, it is acknowledged that conclusions of an exploratory research such as this one are tentative and not conclusive. Further studies of an empirical nature will be required to make conclusive recommendations.

The research focussed on past research papers and selected secondary sources, documents and policies that were analysed theme by theme and section by section, for documents such as lesson plans, mark sheets, exercise books and curriculum documents. All themes used for the analysis of lesson plans, assessments, mark records and learner books were constantly refined during the research process and sought to establish the nature of mathematics and ICT tool affordances and how they address the indicators and sub-elements of retention. Thereafter it was determined whether ICT affordances already, or had the potential to, provide stimulation that help organise mathematics in a better way to enhance retention.

The constantly refined themes used to evaluate all documents were derived from the literature on the nature of mathematics (sequential versus non-sequential, hierarchical versus non-hierarchical, connected versus disconnected) and sub-categories that impact on retention. The themes are as follows:

Themes for lesson plans

1. Practices that address the nature of mathematics
2. Practices that address indicators of retention
3. Practices that cater for the category 'ICT tools'
4. Other contextual factors relevant to the topic
5. Utility and application of lesson concepts
6. Pedagogical practices

Themes for exercise books

1. Practices that address the nature of mathematics
2. Practices that address indicators of retention
3. Practices that cater for the category 'ICT tools'
4. Other contextual factors relevant to the topic

5. Utility and application of lesson concepts
6. Pedagogical practices

Themes for mark sheets

1. Practices that address the nature of mathematics
2. Practices that address indicators of retention
3. Practices that cater for the category 'ICT tools'
4. Other contextual factors relevant to the topic
5. Utility and application of lesson concepts

Themes for studied mathematics curriculums

6. Are the topics sequential or non-sequential?
7. Are the topics hierarchical or non-hierarchical?
8. Is there prescribed pacing or not?
9. Are the topics connected or disconnected?
10. Pedagogical issues

Theme for research papers on the four categories

1. Practices that address the nature of mathematics
2. Practices that address indicators of retention
3. Practices that cater for the category 'ICT tools'
4. Other contextual factors relevant to the topic
5. Utility and application of lesson concepts

Themes for software reviews

Two mathematics applications, MyPedia and Mathletics, were selected purposively because they were available. The following themes were used for analysis:

1. Practices that address the nature of mathematics
2. Practices that address indicators of retention
3. Practices that cater for the category 'ICT tools'
4. Other contextual factors relevant to the topic
5. Utility and application of lesson concepts
6. Pedagogical implications

Reflective memos in the form of diagrams and tables were also provided within the data collection and analysis stage to guide the eventual systemisation of the categories. For all four categories, information that led to the formation of emergent categories was also collected and grouped under the two categories of enablers of retention and barriers to retention. I did not put much emphasis on particular applications but rather on the general formats that address the axial categories in this research.

3.2.1 Phases of the Research

Corbin and Strauss (1990) guided the selection of the following adapted phases of grounded theory research, illustrated in Figure 3-1, that were followed from the initial identification of categories and themes to the stage of relative saturation. It has to be noted that in their original form, the phases would not have met the needs of this exploratory research.

Themes	•Identification of low level categories from literature •Higher level categories derived from literature
Sampling	•Purposive sampling from available documents •Use of available documents
Development of themes	•Research papers used to develop low- and high-level categories
Data collection and analysis	•Simultanous processes of collecting and analysing data from papers and documents
Memos: Tables, diagmrams and reflections	•Written in the form of tables, diagrams, and reflections on enablers of and barriers to retention at the end of each category
Presentation in chapters	•Presentation on each category followed by a semi structured discussion on sources
Synthesis	•Information on the four chapters on categories systhesissed
Discussions and recommendations	•Discussions and formulation of a recommended pedagogical framework

Figure 3-1 Procedures for grounded theory research (adapted from Corbin & Strauss, 1990)

While the first step was to identify themes from Literature, the final stage was the development of a new pedagogical framework based on the four identified low-level and emerging higher level categories. Although the phases of the research are represented sequentially in Figure 3-1, the actual process in most instances occurred simultaneously, for example, during data collection and analysis. So in most instances, an analysis and discussions followed immediately after data was collected. In others, a summary highlighting the major issues raised was used as basis for discussion. In the researches themselves, I did not only rely on findings and conclusions, but important facts and assertions identified in the literature were used to build a credible framework, and the whole research was approached qualitatively. It has to be borne in mind that the stages of grounded research theory were modified and adapted to meet the requirements of this research, something that is permissible in an exploratory research.

Corbin and Strauss (1990) also mentioned other procedures and canons that are part of the grounded theory research. These include accounting of patterns and variations in literature, each category construction being part of building a theory, working with other researchers, and analysing the broader structural conditions that include contextual factors affecting studied data.

3.3 **Research Methodological Approach**

The initial step of the research was the identification of the four broad themes, the low-level categories, for review and analysis from the research topic. These are the nature of mathematics; retention and function in education; ICT affordances; and since learning happens within a context, ideal pedagogical contexts that support technologically mediated learning. Together, they provided enough information on stimulation and tools that enhance the retention of concepts. Information that informed the low-level categories was extracted not only from the findings of reviewed papers but also from different chapters of relevant literature that generated discourse in those papers, because I needed to use all available, relevant literature and findings to make credible recommendations that address the research questions. Sometimes in this type of research, the whole research is not relevant, because there is very little relevant research on the topic, rather it is the assertions and claims made in the research that can hold the key to important and revealing information.

The second step was the development of further higher level themes from the literature on the four categories and the creation of analytic codes (Charmaz, 2006). Analytic codes in this paper consisted of indicators of retention sub-themes that in total addressed indicators of retention. A process of discovering processes and the development of higher level categories through inductive reasoning followed, and at each stage of the research, research questions and categories were constantly being refined. This step involved the analysis of documents on these categories on the basis of the indicators of retention mentioned in the literature.

The indicators of retention, broken down into higher level categories (Figure 3-2) acted as the framework for evaluation and reinterpretation of all categories, including reviewed documents on retention itself. The last part involved the writing of memos and integrating higher level categories into a new theoretical framework.

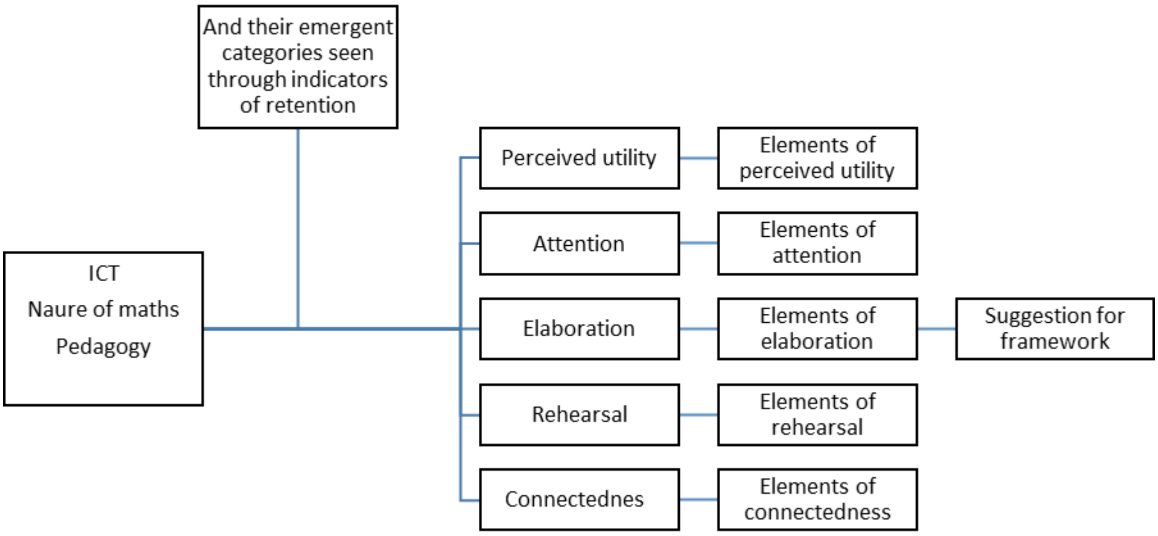

Figure 3-2 The development from low-level categories to emergent categories evaluated through the lenses of indicators of retention and their sub-elements leading to the new pedagogical framework.

The final results were presented in the form of sub-chapters, each relating to one of the four categories, which together with the emergent higher level categories built up a new framework on the use of ICT to enhance retention of mathematical concepts (Chapter 5).

3.4 **Data Collection Methods and Tools**

Selected sources of international and local literature and documents were categorised into the four low-level categories but grouped under the following headings that were used to answer the research questions (Section 1.9).

1. Papers and documents that described the nature of mathematics in any of the selected countries. Few papers on the topic were available in Zimbabwe and Kenya, and I either

omitted or replaced them with papers from countries with similar geographical backgrounds.

2. Documents that uncovered the nature of mathematics.
3. Documents that linked the nature of mathematics to other categories.
4. Papers that support or are critical of retention in mathematics education were included for their potential to initiate critical discussions. These were initially set to be included but none directly addressing the needs of this research were available.
5. Literature that sheds light on retention, ICT use, and the nature of mathematics and pedagogy were selected irrespective of the sections where they were located in the selected research
6. Papers on tool use and ICT affordances in mathematics teaching and relevant studies on ICT mediated mathematics teaching were selected.
7. Manuals and reviews for the selected ICT hardware and software.
8. Grade 8 Mathematics textbooks from a resource shared by both learners and teachers that are considered Curriculum Assessment Policy Statement (CAPS) compliant were selected to study the South African curriculum. A paper on the Finnish model was selected to describe its curriculum. A mathematics syllabus was selected from Zimbabwe to describe its curriculum. Finland and Zimbabwe were analysed in relation to how they addressed the selected themes that address the four research questions.
9. Teaching and learning documents that included mark sheets, lesson plans and work schedules for Grade 2, 3, 6, 7 and 9. Initially 10 papers were selected to be reviewed, but only four were needed to reach a point of relative saturation.

3.4.1 Exclusion of Sources

Initially, the research did not focus much on research done on technologies in other subjects, as these were not deemed to be exactly comparable to mathematics, which is considered sequential and hierarchical in this research. However, in certain instances, lack of sufficient relevant papers in mathematics necessitated a revisit of that criteria.

Research papers prior to 1990, unless they were considered essential, and in any language other than English were given limited consideration. This was done to reduce temporally induced transcription errors that could distort the findings.

I had to also exclude lesson plans and/ other documents that were submitted but deemed to be unauthentic. After a verification process, certain lesson plans were deemed unfit for the research purposes because they seemed to have been adapted to meet my ‘expectations’. These included the four lesson plans ‘from Kenya’ and three ‘from Zimbabwe’. Papers from Zimbabwe, Kenya and a few other countries that did not shed greater light on the topic were excluded, and this might influence the generalisability of this research. These glitches were anticipated since this is arguably a pioneering study on the topic.

3.4.2 Sampling and Inclusion of Sources

The sources were selected using purposive sampling of papers that met the inclusion criteria. The rationale for purposive sampling was that there is limited research on the topic or relevant literature are unavailable. Relevant issues on pedagogy were raised from all literature studied in the research. More lesson plans from South Africa than from the other countries were included in the research, mainly because they were available. I consulted many more documents than I initially envisaged to check for patterns. I also used two lesson plans from Zimbabwe and none from Kenya. The curriculum and a lesson plan from Finland was inferred from literature. Reviews on Mathletics and MyPedia were conducted because I managed to access the relevant documents. The research papers and journals mainly originated from countries meeting the following criteria:

1. Countries that have been successful at teaching mathematics and integrating technologies in mathematics teaching, as evidenced by their TIMSS rankings. Papers from Finland, the USA and the United Kingdom were of particular interest based on this criterion. It was important to understand, especially for countries such as Finland and the USA, how the papers addressed the selected themes. The USA was mainly selected for its experience in using iPads. Data was collected and analysed from all sections that had information relevant to the study.
2. Other African countries (Kenya and Nigeria) that use ICTs in mathematics education and/or cater for retention or demonstrate practices that support/or do not support the retention of concepts in mathematics education. These were initially selected for review, but very little literature on the subject was found. In the absence of adequate papers on

the categories under study, practices and teaching documents were reviewed to verify whether or not these categories were implied in any way in the teaching of mathematics.

3. A South African experience, especially how well resourced and successful schools are in teaching mathematics, structuring their lessons, and using ICTs tools to promote mathematics performance.
4. Documents and literature that included peer review papers, policies, assessments, lesson plans and other relevant documents from South Africa and the selected countries. The main purpose for including these was to look for the following themes: Pedagogical issues, assessments, the curriculum, tools, the various factors that promote retention, and an enabling pedagogical context for ICT mediated mathematics learning.

Again, I acknowledged that the lack of randomisation in the selection of lesson plans and other assessment documents could have potentially compromised the validity and reliability of the findings.

Table 3-1 shows the selection criteria for literature sources based on terminology related to the research. Not all sources that met the outlined criteria were considered because another more stringent criteria outlined by Scott (1990) was used to assess the quality of sources. Scott outlined the following criteria for handling documentary sources and assessing their quality:

1. Authenticity: The process required for the assessment of evidence in terms of integrity, unquestionable origin and for being genuine. This criterion led to the rejection of a lot of the submitted record sheets and lesson plans that I felt had been doctored to show a favourable review.
2. Credibility: All the documents used were assessed to check for errors and distortions. Here, I disregarded software review documents that were compiled by programme developers as these were deemed unbalanced and meant for advertisement purposes.
3. Representativeness: Documents were checked to see whether the evidence was typical of its kind, and if not, whether the extent of the variation was known?
4. Meaning: This criterion was used to help ascertain the clarity and comprehensiveness of sources used.

In order to carry out a successful qualitative analysis, a qualitative analyst should keep the following in mind:

- Their biases and preconceptions
- Know their question
- Seek creative abundance, and consult others for alternative interpretations. The selection of further papers was meant to achieve this objective with the hope that the already selected categories would be subjected to scrutiny from new data and be further refined to make them more credible.
- Be flexible
- Exhaust the data selected for inclusion in the research. In my case, I included all relevant data from any selected chapter of research as well as selected portions of data from a variety of documents.
- Celebrate anomalies
- Get critical feedback
- Be explicit through sharing of details with oneself and others (Miller & Crabtree, 1999)

3.5 **Data Bases**

Terminology related to the research was searched in the following databases and sources: Google scholar, Elsevier, Wits library, government documents, and others, as illustrated in Table 3-1.

Table 3-1 The selection criteria of the literature sources was done according to terminology

Data Bases	Terminology	Articles Selected
Google Scholar Elsevier Wits library Government documents International publications	Retention Memory Application Understanding ICT affordances and constraints Information technologies	14 articles[Excludes other documents not available on data bases]

The number of sources of data and the categories they addressed are listed in Table 3-2. The table clearly indicates the many overlaps among the categories.

Table 3-2 Sources of data (N≈49) (≈ used due to overlaps)

		Category Mainly Addressed			
Sources of Data	**Number**	**Nature of Mathematics**	**Retention**	**ICTs**	**Pedagogy**
Research papers	14	√	√	√	√
Lesson plans	18	√	√	√	√
Learner books	5	√	√		√
Mark records	5	√	√		√
Learner assessments	2	√	√	√	√
Curriculum documents	4	√	√		√
Software reviews	2			√	√

As had been expected, there were a lot of overlaps and convergence in the papers and documents from where data was derived. The classification of sources of data under the different categories were in certain instances based more on arbitrary considerations based on the category the source is mostly inclined towards. While (N) was meant to be below 49, categories were explored until a stage of theoretical saturation had been reached. From the onset in the proposal, as has indeed happened, it was mentioned that there was a possibility that the sample size could be more or less than the initial envisaged 20, depending on when saturation was reached. ICT affordances reached saturation on eight papers; mathematics on two papers and thirty documents; retention on two papers; and for pedagogy I felt that two papers and 32 documents were sufficient to reach the relative saturation required for the research's purpose. I ended up looking at many lesson plans to verify variability, connections and other themes that could only emerge from looking at a variety of sources.

3.6 **Data Collection and Data Analysis Approach**

For this type of research where documents have to be reinterpreted, it was deemed not only possible but ideal to simultaneously conduct the stages of data collection, analysis and discussion. This was done in many portions of this research. As a result, in most cases as data was being collected, it was also being described qualitatively and analysed on the basis of how it impacted the identified categories following the structured framework adapted from Corbin and Strauss (1990). The simultaneous data collection, analysis and discussion required references to other authorities to happen, and in the process, almost masking the paper or document under discussion. The separation of these documents were therefore intended to assist with organisation and not for purposes of exclusive focus during analysis and discussions.

Notes and observations on all categories were made prior to writing the data collection and analysis section. As a result, I could criss-cross across the categories through 'omniscient narration' because all the required data was already available. This meant that findings on the last category, for example, were incorporated in the first, the second and the third category and vice versa. The data and rough memos collected before compilation of Chapter 4–6 made this possible.

Documents and literature sources from the identified country groupings were analysed in relation to the seminal research findings on the core categories of this research, highlighted in the literature section and further developed during data collection and interpretation. The second process involved scanning abstracts and documents for relevance to the themes and contexts highlighted in the study. The broad categories that addressed the research questions are listed in Table 3-3 as well as in the other tables that guided the process of writing memos.

The four categories and their sub-elements were used as a basis for the evaluation of documents and researches dealt with in this research. The interaction among the categories is not restricted to their lower levels alone.

Finally, I adopted a semi-structured discussion approach to dealing with a data source, for example, when dealing with a paper or document, a heading gave guidance on the type of source being referred to. However, in the discussion of a point of interest within the selected document, reference was made to other authorities and documents beyond the paper being focussed on.

While the indicators of retention were used as lenses to evaluate other categories, I also evaluated other papers and documents on retention during data collection to refine that category even further. Papers and documents were also used to refine the category on the nature of mathematics. The rationale for this was that although the indicators and the three sub-elements of mathematics were already identified, I thought that more information collected during data collection was needed for the categories to reach the stage of saturation required towards the recommendation of a new pedagogical framework.

Table 3-3 lists some of the themes that guided the analysis of both hard data from the quantitative researches and soft data from qualitative sources. It also lists sources mainly used to address the identified themes as well as the framework of interaction among the categories used as a basis for discussion during data collection and analysis. The framework for analysis below confirm the interconnections and interaction among the four indicators. Memos in the form of diagrams, notes on enablers of and barriers to retention, and tables helped with the reflection and summarising of key issues in each category and at the same time 'lengthening the thematic tentacles' used for systematisation later in the research.

Table 3-3 Research matrix used to collect data showing contexts for all the selected countries

	Criteria			
	View of mathematics as seen through research papers, classroom practices and indicators of retention	Pedagogy and practices, and how they address indicators of retention	ICT software and hardware, and how they address indicators of retention	Retention papers, and how they address issues of retention (until theoretical saturation)
Sources of information studied and analysed	Curriculum Lesson plans Mark sheets Assessment papers Exercise books Research papers	Curriculum Lesson plans Mark sheets Exercise books Research papers	Research papers ICT manuals Reviews	Research papers Indicators of retention curriculum Lesson plans Mark sheets Assessment papers Exercise books
Main framework for analysis	1) Indicators of retention and sub-elements: 2) ICT affordances 3) Nature of mathematics	1) Indicators of retention and sub-elements: 2) ICT affordances 3) Nature of mathematics	1) Indicators of retention and sub-elements: 2) ICT affordances 3) Nature of mathematics	1) Indicators of retention and sub-elements: 2) ICT affordances 3) Nature of mathematics

Because of practical considerations, it was not possible to collect learner books from Zimbabwe, Kenya and Finland. All findings on learner books were based upon the available South African books.

It has been mentioned that the category of retention is one of the axial categories of this research whose development started in Chapter 2 and is refined in Chapter 4. The category was used as a lens from which to initiate the study of a data sources. Considering that most of the sources would probably not have within them the actual words like ‘retention’ or ‘indicators of retention’ or even any of the actual indicators, words that denote or imply the presence of indicators of retention were highlighted in advance to guide the research, as indicated in Table 3-4. The same is equally true for the nature of mathematics where the words ‘sequence’, ‘hierarchy’ or ‘connections’ might not appear, and yet, certain practices confirmed their presence, as shown in Table 3-5.

Table 3-4 Data collection matrix showing sub-categories of retention indicators used for coding observations into indicators of retention

Indicators								
Higher level categories	Elaboration	Connectedness	Perceived utility	Attention capturing and interest	Practical component (under elaboration)	Primacy recency (under attention)	Encoding specificity	Rehearsal/Practice
Explanations	Explanations	Linking with other concepts done already	Solving of real life situations	A description of facial, body language	How many opportunities for manipulation?	A description of introductions and lesson conclusions	Similarity of learning and testing context	How many times a task is tried
Offering of further examples to explain concept	Asking questions	Linking with everyday knowledge	Feedback by the ICT tool	Eagerness to engage Interest component	How many opportunities for research?	How do lessons start?	Similarity between learning and testing methods	How many times a task is tried before success
	Using other ways of explaining the concept	Connections through group and pair competitions	Feedback by the teacher	Occurrences of laughter, sharing, and asking	How many opportunities for real life authentic situations?	How do lessons end?		How many observed times learners moved to the next level
	Explanations and help from peers	Connections between the traditional and modern ICT linked teaching methodology	Feedback by the peers	Competitions against self and others Feedback and motivation				How many observed times learner moved backwards and forwards
				Self-directed and efficacy or reliance on teacher instructions				Number of items practised per given time

To determine the nature of mathematics, one of the low-level categories, the secondary categories namely sequential, hierarchical and connected mathematics were selected. Emergent higher level categories were initially selected to determine the nature of mathematics taught in South Africa, Finland and Zimbabwe.

The three secondary were further broken down into higher categories (Table 3-5) used to initiate the evaluation of curriculums and documents relating to the nature of mathematics. These, as has been explained, were refined as shown in Figure 5-2 after engagement with literature. The nature of this research allowed these steps of refinement and back and forth discussion.

Table 3-5 Showing the initial matrix of elements used for coding the nature of mathematics. The matrix will be developed after engaging literature and documents on other categories relating to the nature of mathematics.

	Nature of Mathematics		
Higher Level Categories Of Nature Of Mathematics	**Sequential**	**Hierarchical**	**Connected**
Catering for multiple learning styles (multimodality)		√	√
Back and forth movements			√
Simplex to complex, known to unknown	√	√	√
Number of exposures to concept		√	
Application of concepts		√	√
Collaboration opportunities		√	√
Marking and feedback	√	√	
Differentiated assessment	√	√	√
Class teaching			√
Learner achievement before next lesson	√	√	√

3.7 **Interpretation and the Research Report**

The process of reinterpretation was ongoing and became part of the data collection and analysis, writing of memos, coding and integration of the low-level categories, other higher level categories and even ‘tertiary level’ categories that emerged into a pedagogical framework. The results section of the grounded research methodology was the longest and the results were presented as chapters as indicated below. It should be noted that there were a lot of overlaps in the categories as well as in the sources that describe them. The data collection and analysis process followed the order described below.

The chapter on the nature mathematics mainly consists of research documents that deal with the nature of mathematics. Various curriculums, assessment records, lesson plans as well as a variety of other documents highlight the nature of mathematics from a policy and practical perspective. Although documents such as lesson plans fit in well in this chapter, I grouped them under pedagogy because they address that category as well.

The chapter on retention focussed on the function of retention in mathematics and its sub-categories. The chapter starts with the low-level category that was developed into higher level categories from literature and documents. Because of its importance in the research, relevant papers were reviewed to further refine this category.

The chapter on ICT tools narrows down the focus to iPads, tablets, calculators, video-based contexts and the one application MyPedia. This chapter deals with ICT affordances that enhance the retention of mathematics and its sub-categories as diagrammatically represented in Figure 3-3.

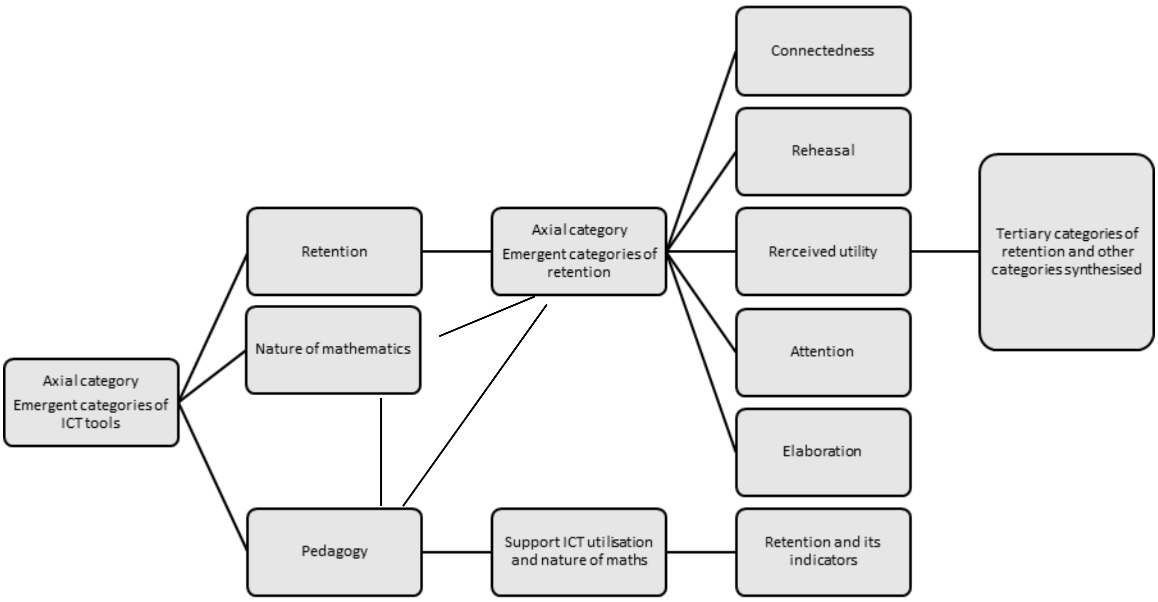

Figure 3-3 A schematic representation illustrating how ICT affordances and their emerging sub-categories directly or indirectly interact with retention (as summarised by its indicators) and other categories to enhance retention of mathematical concepts.

The low-level categories of ICT tools and retention have a lot of detail in their chapters because retention was one of the two axial categories through which all the other categories were evaluated (Figure 3-3), and also because ICTs afford and is dependent on the other low-level categories (Figure 3-3).

The chapter on pedagogy once again permeated all the other categories as well as the teaching documents that were studied. These included the lesson plans, summary mark sheets, mark records, assessment plans and learner books.

In the last chapter on the recommended pedagogical framework, all the low-level and their emergent categories were systematised and fitted together into a usable, broad pedagogical framework with elements recommending how ICTs should be used to promote the retention of concepts. Drawing from all the reviewed papers and documents, this chapter sums up the answer that addresses the research question 'How do ICT enhance the retention of mathematical questions?' The chapter's purpose to offer a broad, systematised framework on how ICT could be used to promote the retention of mathematical concepts as illustrated in Figure 3-4 was deliberate in order to avoid dealing with individual or specific ICT tools. This is important if one considers the rapid changes and the infinite types of both software and hardware tools that are either currently being used or designed to support mathematics education.

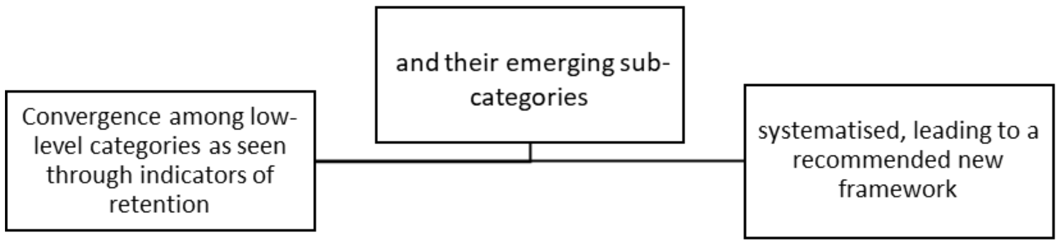

Figure 3-4 A summary of how low-level categories and their emergent sub-categories were used to form a new pedagogical framework on how ICT should be used to enhance retention of mathematical concepts.

As can be seen from the above explanation that guided this research, all the categories were studied in silos but each time the analysis incorporated elements that addressed the interconnections among ICT tools, retention and the nature of mathematics, themes that addressed indicators of retention.

The low-level category of retention was broken up into indicators of retention in the literature section and 'exported' for use in the data collection and analysis section where they are further refined through literature and used as lenses through which the other indicators were evaluated.

3.8 **Validity, Credibility and Reliability**

The nature of this research, practical considerations of time and space together with the purposive sampling used in this research opens this paper to accusations of subjectivity. To mitigate this, triangulation, thick, rich descriptions and peer debriefing were used as some of the validation strategies to eliminate the possibility of subjective conclusions that would have negatively impacted the validity of the results. Cross referencing, verification of literature and wide consultation on thematic approaches to the analysis aided in validation, thus allowing for the emergence of a credible pedagogical framework on how ICT could be used to enhance the retention in mathematics education. The following criteria, as has already been mentioned, was also used to address issues of the validity, credibility and reliability of sources:

1. During the authentication process, I checked whether evidence was corroborated and genuine and whether it was from impeccable sources. Policy documents, textbooks, peer reviewed publications and statistics already in the public domain were also used to enhance the authentication of sources, and consequently, the findings of this research.
2. Checking for credibility involved evaluating whether evidence gathered was typical of its kind, especially based on the findings of previous research and information in the public domain. This was especially important especially in the verification of brochures used for reviews, lesson plans and marks.
3. Representativeness was ensured by evaluating analysed documents and literature to check if they were representative of the totality of relevant documents. The difficulties of purposive sampling are that even in the documents selected it does not provide a true reflection of the actual situation in all schools.
4. Meaning was ensured by evaluating the evidence on whether it was clear and comprehensible.
5. Toulmin's framework (Toulmin, 1958) illustrated in Figure 3-5 below on whether claims made were understandable, have been substantiated and are of considerable significance was also used to justify the elimination and inclusion of certain sources and conclusions used and reached, respectively, in this research.

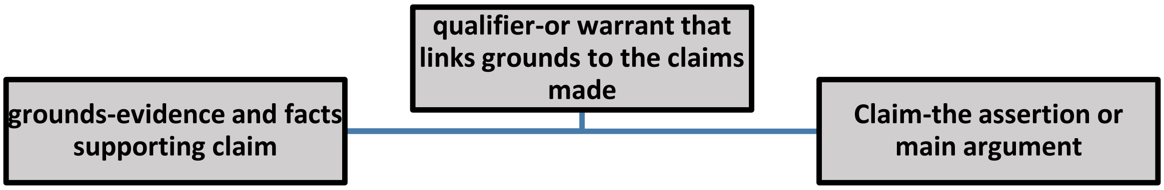

Figure 3-5 Toulmin's framework. (Adapted from Toulmin, 1958)

I do, however, acknowledge that the purposive sampling method used to collect crucial documents led to a likelihood that some of the data is not truly representative of its kind.

3.9 **Ethical Considerations**

The nature of this research required only that all literature and documents used be referenced in and out of the text. Texts, documents used and literature from where data was derived are all listed in the Annexure section. With the exception of DoE documents, all submitted documents such as mark records and lesson plans had the names of their schools and teachers removed to maintain anonymity.

3.10 **Conclusion**

A grounded research methodology was used to reinterpret and make observations on the documents available on the four low-level categories. The category of retention has already been broken down into a secondary category in the form of indicators, and upon refinement from literature in the data collection section, were further refined into tertiary categories that were used to formulate a new framework on the use of ICT to enhance the retention of concepts. Similarly, the nature of mathematics starts with a broad categorisation of connected, sequential and hierarchical mathematics and a few emergent higher level categories to initiate evaluation of documents and papers. The data collection, analysis and discussion happened almost simultaneously. Reflection memos mainly took the form of diagrams, tables and notes on enablers of and barriers to retention at the end of observations from a document or paper.

CHAPTER 4: DATA COLLECTION AND ANALYSIS

Before setting out the collection and analysing of data, it is pertinent to link this part of the research to the essential elements of the problem statement and research objectives and questions in Chapter 1 as well as the categories in Chapter 2.

Evidence presented in Tables 1.1 and 1.2 indicate that most learners are struggling in mathematics. Based on Perkins's (1991) view on the basic goals of learning, another way of saying this is that challenges in mathematics are a result of a failure to understand, retain or apply mathematical concepts. Claims have been made that ICT tools have the potential to enhance the retention of concepts (Laurillard, 1993), and yet very little research has been undertaken to establish the veracity of these claims, especially considering how diverse these tools are in terms of their affordances and constraints (Chinn, 2000). That question cannot be addressed without verifying how schools view mathematics, for example, whether it is an objective, hierarchical and sequential subject or not (Chinn, 2000; Wilson, 2009). The role of retention and how it is catered for in the subject and the description of the pedagogical setting that supports retention of mathematical concepts are guided by how mathematics is viewed, especially by the teacher who implements their understanding of the curriculum in practical terms (Kennewell, 2006). The nature of tools themselves and the variations in their affordances and constraints require exploration in broad terms because of their diversities.

The research aim was to gain insights from the selected data sources to construct a pedagogical framework that guides the effective use of ICT to enhance the retention of mathematical topics. The aim not only guided the nature of the data collected, but also directed the selection of the categories that helped address it.

The aim was divided into the four objectives that together address it and the research questions fully. Each research objective has a corresponding research question and a corresponding low-level category to ensure that all essential components of the research are catered for during data collection and analysis (Table 4.1).

Table 4-1 Showing research objectives with their corresponding research sub-questions

Research Objective	Corresponding Research Sub-Question	Corresponding Category
To establish the nature of mathematics	What is the nature of mathematics?	Nature of mathematics
To establish the importance of retention in mathematics education	What is the role of retention in mathematics education?	Retention
To establish how the use of ICTs contributes to retention of mathematical concepts	Which ICT affordances enhance retention of mathematical concepts?	ICT tools
To provide a pedagogical framework for using ICTs to support retention of mathematical concepts	What is the pedagogical framework that supports the use of ICTs to enhance retention of mathematical concepts?	Pedagogical practices. This chapter was left open to allow for the analysis of observations to become the basis of recommended practices

The stages of data collection and analysis were conducted almost simultaneously based on the major themes or the selected low-level categories: The nature of mathematics, retention, ICT tools, and pedagogy. The process was presented in four sub-chapters, outlined above, for each category and in Chapter 5 that synthesised the findings from each of the categories together with their emerging higher level categories. It must be noted that the recommendations provided emanate only from the literature and documents consulted and analysed; a different set of literature would probably have led to a totally different finding.

4.1 **General View on the Categories**

The four main low-level categories of this research are mathematics, retention, ICT and pedagogical contexts. These low-level categories were reinterpreted through available data to formulate secondary, and in some instances, tertiary level categories that impacts on the retention of concepts. Literature for reinterpretation was derived from international, regional and local primary sources until a point of saturation. Such saturation is relative as it only relates to the selected documents and papers. No further engagement with literature was necessary after a stage of saturation had been reached. All four categories appear in both the literature review and the data collection and analysis stage, because the categories as they are reviewed in literature was used as lenses through which related papers and documents were analysed in the data collection and analysis stage, with all four categories again being evaluated on how they address the research questions and relate to indicators of retention.

4.2 **ICT Reviews**

The themes for ICT reviews were categorised under hardware and software tools. The focus for hardware components was placed on practical considerations such as portability, connectivity issues, printing and generation of reports, dependence on data, and whether their nature predispose them to distractions. The focus for software was placed on their ability to generate reports, variation of complexity, immediate feedback, interactivity, contextualisation of concepts, rehearsal opportunities, multiple representation formats, collaboration, and whether they cater for different learning styles.

4.3 **The Nature of Mathematics**

This sub- chapter deals with document analysis that allowed the research to make a comparison of curricula of the selected countries.

The study on the first category, the nature of mathematics, was guided by the following research objective and question:

Research Objective

To establish the nature of mathematics

Research Question

What is the nature of mathematics?

This category was firstly explored to establish, using the goals of education, and specifically, the indicators of retention and their sub-elements, if mathematical achievement is related not only to the way the subject is viewed through official policy documents, but also to how it is practically viewed or implemented by teachers in the classroom. Secondly, because the nature of mathematics is suggestive of the ICT affordances and pedagogical strategies that best support the teaching and learning of the subject to enhance the retention of concepts.

The general view of mathematics studied showed that in general all mathematics curriculums from different countries confirm in theory that it is accepted that mathematics is taught from known to unknown and that concepts build on and are connected to each other. The evaluation of curriculums also showed in varying degrees that opportunities to practice and apply mathematical concepts are essential. With the exception of Finland where the curriculum is not detailed, there are not many differences among the curriculums studied to warrant the differences in performances in the studied countries' mathematics performance. I assumed that there would be significant underlying factors that could be attributed to the difference in performance; hence, the need to practically verify the teachers' understanding of the nature of the subject. I also discovered that from a curriculum point of view, other than the amount of detail, there is not any single notable factor that places Finland ahead of South Africa and other countries not performing very well mathematics, because if anything, the Finnish curriculum is deficient in detail. Rather, it is the differences in the elements of the pedagogical context in its entirety that seem to be hugely influential. Alternatively, and strangely, the differences in performance could be hidden in the detail, or lack of it, in the curriculum.

Just like the other documents, the curriculums of South Africa, Finland and Zimbabwe were evaluated in 4.3.1 on whether they are structured to cater for and use the indicators and sub-elements of retention. The was done by verifying whether the topics and concepts were sequential, hierarchical, connected and whether opportunities existed for retention and ICT tools to support its indicators at the curriculum level.

4.3.1 The Finnish Curriculum

Finland was selected for this study because it is one of the countries that is doing particularly well in both the Programme for International Student Assessment (PISA) and TIMSS mathematics assessments. Malaty (2004) actually argued that "teacher education in Finland could represent for educationalists an ideal efficient case" (p. 1). The country is well resourced (Malaty, 2004); the teaching profession in Finland attracts the best professionals who are motivated and have good mathematical content knowledge; and all teaching practices in Finland demonstrate an excellent pedagogical context that promotes and leverages resources to enhance mathematical learning. They are definitely doing something right, which is why this research sought to establish not only the country's view of mathematics, but also of retention, ICT tools usage, and the practices that allow them to succeed in mathematics teaching. What is baffling about the Finnish curriculum is that it is neither dense nor prescribed; teachers also have lot of autonomy to arrange concepts and assess as they see fit.

In Finland there is almost no information on the role of technologies in teaching mathematics. The only essential aspects in Finland are the outline in the National School Curriculum and teacher education. The planning, implementation and assessment are left to individual class teachers. Other important aspects worth noting in the Finnish approach are that teachers teach for understanding and apply skills learnt to other situations. Not much literature is available on whether the concepts are retained. The approach focuses on improving confidence in the subject, support, and differentiated instruction. This is possible because the classes are small. This can be compared to South African schools where the teacher to learner ratio in most schools is about 1:40. There is less detail in the national curriculum and more in the local curriculum. Compared to this, South Africa's national curriculum is quite detailed and prescriptive and offers specific timeframes and sequencing of topics. This has many implications, including the flexibility for teachers to move according to the needs of the class.

Venkat and Spaull (2007) established that most South African primary school teachers have inadequate content and pedagogical knowledge in their subject. While on one hand, all Finnish teachers have to do a practical teaching practice in mathematics which is important because all teachers, irrespective of their specialisation, can connect their knowledge of mathematics to other subjects, in South Africa, especially in primary school, this has not been the case.

Finnish teachers present mathematics ideas by sharing and verbalising ideas. Although the research does not explicitly show whether retention has a function in Finnish mathematics, it is implied in the way it is taught. Verbalising ideas rank very high on the retention pyramid to support retention. This confirms the folly of adopting wholesome e-learning programmes that do away with social strategies that have proven to be useful in mathematics learning. A wholesome uptake of ICT that excludes other strategies could prove to be counterproductive.

Learners with difficulties in mathematics are supported (promoting prior knowledge and skills) and given opportunities for differentiation. Research also confirms that such intervention is mostly provided during the elementary stages of learning (Sahlberg, 2012). Manipulatives are used to prevent misconceptions. Sometimes resources that can be manipulated enhance understanding, which is the basis of retention. ICT tools have simulated manipulatives that allow learners to test their understanding of different concepts. The advantage of concrete objects over simulated ones, in instances where there are misconceptions, is quite apparent.

Textbooks play a big role in Finland, and a study by Niemi (2004) indicated that 53% of Finnish teachers are satisfied with their textbooks in Grade 6. Textbooks do play a role and are not inferior to a basic e-Book that lacks interactive content. ICT tools that replace the hard copy textbook should possess greater affordances that allow learners to interact with content at a deeper level. Finnish textbooks are logical and explicit, and essential facts are connected to everyday life, and they compare very well with the South African textbooks studied in this research. The Finnish textbooks cater for different learning styles with colourful illustrations and varied exercises. This shows that with the exception of offering authentic and simulated environments as well as the interactivity affordance of most technological learning applications, textbooks can also do many things afforded by ICT. The major difference is probably the immediacy of feedback, interactivity and the interest component attached to gamification. However, for most schools, over time eBooks cost a fraction of hardcopies. The homogenous exercises in textbooks can be used for average learners while the ICT tools cater for very fast and slow learners.

Localising content is equally important for both textbooks and eBooks, allowing learners to make connections between what they learn and their real lives. Learning materials in Finland are produced by ordinary teachers who are familiar with local conditions.

In the study by Malaty (2004) on mathematics teacher training in Finland, the following very important issue was raised: There is free access to computers and printers, and all computers are linked to the internet. Easy and free internet access has many implications for both hardware and software use in class. It also influences whether schools should completely move towards technologically-based education or whether they can adopt elements of blended learning. For example, when internet is inaccessible and expensive and cannot connect all gadgets, would it still be beneficial to stick to a ‘superior’ tool that is not adding value to the learning experience? Access to programmes that require internet, like Khan Academy and superior packages of Pearson eBooks, would remain a dream to many schools that lack internet connectivity, which should be readily available for schools as part of social justice.

In Finland, teachers’ work is not subject to regular supervision, meaning they have a lot of teacher autonomy (Malaty, 2004). This suggests the level of competence and motivation of Finnish teachers. This autonomy gives teachers space to pace and arrange the topics in mathematics according to the specific needs of their mathematics classes, leading to a responsive teaching approach. Autonomy allows teachers to spend less time on topics learners understand and more time on topics that require further teaching. It is not surprising that although Finland apportions the least time to mathematics teaching, its results are far better than most countries that spend more time. This is where prescribed pacing fails: It presupposes that learners from different geographical and economic backgrounds will learn at the same pace across the country.

Finnish classrooms are not noisy or disruptive, and learning is used to the maximum. This is supported by learners learning close to home and an open door for visitors. This again suggests a physical connection between home and school that is essential for mathematics teaching that support the retention of concepts.

The local curriculum is developed by municipalities and teachers. Education is therefore localised and in a sense 'owned' by those who teach it. The context of learning is not designed by someone who is not directly related to the implementation process and in the process makes unreasonable demands on teachers to finish a certain number of topics within a certain time period. Each normal school is part of a university (Malaty, 2004). This mainly means that learning and teaching in Finnish schools is research driven and that the pedagogical and content knowledge of teachers is excellent. The advantage of research driven teaching is that educators can use data to plan interventions and focus on specific needs. Teachers need a master's degree in education, meaning teacher's increased pedagogical and content knowledge allows them to represent concepts in multiple formats.

Grades 1–6 Finnish teachers are class teachers and usually move up with their classes for a few years (Malaty, 2004). The high levels of education among teachers make it possible for them to move to the next grade as their students progress through school. That allows teachers to take advantage of the prior knowledge of classes and individual learners and provides them with more time to build connections. It is well-known that new teachers usually take a long time to figure out the ZAD of classes and individual learners (Gee, 2012). The whole first term is probably spent on this, and compounded with the lost time at the start and end of term, approximately four months of school time is 'wasted'. This could be one of the sources of mathematics problems in South Africa. Allowing class teaching in the primary school is probably the best decision Finland has made.

The low teacher to learner ratio support individualised learning based on each learner's needs, taking into consideration their individual ZPD and allowing the teacher to provide differentiated teaching. The low ratio allows individual learners to benefit from their own learning path and get immediate feedback. Secondly, it is easier for the teacher to establish and scaffold learning to individual learners' prior knowledge. In the South African context, reducing the current ratios of 1:40/50 to less than 1:20, as in Finland, would have serious financial implications. The role of ICT programmes in assisting individualised learning cannot be overemphasised (Morrison, 1998, in Chesitit, 2015). Individualised learning already discredits uniform pacing of mathematics learning. Each learner is provided with a firm background that makes it possible for them to understand concepts before they move on to the next topic, with that understanding being the basis of any further learning.

In Finland, class teacher education, the major field of study is education and not subjects. This is very important since it breaks the compartments between subjects. Neither life nor education is compartmentalised according to subjects; it is integrated. While there are advantages to training teachers to be experts in subjects at primary school, the main benefit of concentrating on education rather than subjects is that teachers can infuse and apply mathematical concepts across subjects, and in the process, support elaboration and connections as well as their perceived utility in different contexts.

The focus of Finnish teacher education is games, problem solving and teaching that enhances understanding (Malaty, 2004). Games enhance motivation, attention, interest and on task staying power, all of which are essential for retention. The success of Finnish teacher education is due to the required high teaching qualifications and the success in recruiting motivated teachers (Malaty, 2004).

There are no private lessons, probably because Finnish schools maximise the use of learning time with no unnecessary distractions and mathematics learning is integrated with other subjects, improving mathematical understanding. If this is the case, then time allocated to mathematics should not be measured in terms of minutes, but in terms of its qualitative utilisation. The little learning time used with overlaps, games, individualised learning and support together with connections have the potential to exponentially increases learning achievement. In the UNESCO survey of 1986, the collected data from 27 European countries showed that for teaching mathematics at schools, Finland devoted the least time compared to any other European country included in the survey (UNESCO, 1986). The findings by Malaty (2004) are summarised in Table 4-2.

Table 4-2 A summary of findings of the paper by Malaty (2004) on mathematics curriculum in Finnish schools.

Practice	Possible Impact on Retention	Possible Implication on ICT Tool Use
1) Class contextualised teaching	Perceived utility and connections	Affordance of ICT-virtual environments
2) Learner contextualised teaching	Perceived utility and connections	Affordance of ICT-virtual environments
3) Independent pacing	Promotes conceptual understanding and use of prior knowledge and understanding	Scaling up and down affordance of ICTs
4) Lack of disturbances	Maximisation of time allows for practice and opportunities to make connections	Any time availability provides opportunities for practice
5) The motivated teacher	Makes learning interesting, increasing attention and understanding of concepts	Gamification promotes motivation and increases attention
6) Locally designed curriculum	A locally designed curriculum is relevant to the learner and considers their needs and prior understanding. Learners are not unnecessarily hurried to keep abreast with official pacing.	Affordance of ICT-virtual environments
7) Class teaching	Connectedness between subjects and concepts, elaboration, and utility of information from one context into another	Easier to set learning programmes that integrate different subjects
8) Low teacher/learner ratio	Individualised prior knowledge	ICT affordances allow for individualised learning
9) Continuity	Connectedness between subjects, grades and concepts Less time wasted while establishing baseline understanding	Storage affordance and pedagogical framework allow learners to be taught, but the same teacher over a good number of years
10) Independent sequencing according to need	No time constraints in terms of practice and elaboration opportunities	No human teacher can do this. Only ICT can be used to individualise learning
11) Very strong intervention	Promotion of prior knowledge ensures that learners' retained knowledge is strong	It is easier to establish and ensure that learners' prior knowledge is taken advantage of
12) Focus on games	Games add an interest component and increase stay time and attention	Gamification affordance

4.3.1.1 The Nature of Finnish Mathematics

To address the first research question based on the Finnish curriculum, literature showed that Finland uses sequence, connections and hierarchy well to teach mathematical concepts by using grade teaching and teaching a class for consecutive years. The focus on education and not subjects as well as the consecutive years that teachers teach their classes indicate the interconnected nature of the mathematics taught in Finland. The application of concepts in different situations and the whole interconnected system of education enrich conceptual descriptors that enhance retention. As a result, the success of Finnish mathematics education cannot be attributed to a single factor.

4.3.1.2 Enablers of Retention

Finland encourages active engagement, which not only promotes understanding, but also leads to better attention and conceptual encoding (Perkins, 1999). Strengthening foundational knowledge supports understanding, and in turn, positively supports retention. Finland also caters for all learning styles using resources and actual teaching. Concepts taught in Finland are applied in different situations, supporting perceived utility, elaboration, and building of connections. Pedagogical practices such as grade teaching and teaching a class for many years strengthens connections and builds on prior concepts, thus supporting the correct sequencing and hierarchy of concepts.

4.3.1.3 Barriers to Retention

There is not much in the literature about rehearsal, practice or even how often the learners are assessed in different grades by different teachers. Because the teachers have autonomy, it is assumed that these decisions are left to the teachers. The superior affordances of ICTs in mediating mathematics learning were not emphasised. The implication would probably be that ICT are simply viewed as other tools that are used if and when necessary.

4.3.2 The Zimbabwean Curriculum

This section discusses the Grade 4–5 Zimbabwean syllabus that was analysed. There is no prescribed pacing in the curriculum, although there is evidence of sequencing and hierarchy, and the pacing is determined by the needs of the class. Learners are encouraged to work hard.

Learners must understand the completed before they do new work. The aims of the Zimbabwean syllabus include focus on conceptual understanding, preparation for present and future studies (application and retention), the need to understand key words, and the development of skills through appropriately challenging mathematically related tasks (understanding and application). The objectives are closely related to the goals of Perkins (1991) and include recall, recognise, application, solving and interpretation. The skills are weighted and categorised, as shown in Table 4-3.

Table 4-3 Weighted skills in the Zimbabwean curriculum

Knowledge	16%
Routine manipulations	38%
Understanding and application	36%
Problem solving	10%

(NB. The potential for high use of retention of foundational concepts include, but are not limited to, tables and bonds)

The distribution shown in Table 4-3 provides opportunities for learners to understand, retain and apply concepts. The depth at which this is done is subject to discussion. In this research, application includes problem solving and the other higher order applications of the concept in Blooms's taxonomy.

The scope and sequence of topics is presented incrementally per grade. There are no timeframes and many baseline activities to verify prior understanding. The curriculum provides many recall opportunities with mental exercises and recognition activities, leading to generalisations. There is a sequential and hierarchical presentation of concepts, advocating for the use of concrete media, especially in primary school.

4.3.2.1 The Nature of Zimbabwean Mathematics

Zimbabwean mathematics meet the criteria for a sequential, hierarchical and connected subject. While connections among subjects may be different from and not as extensive as the Finnish scenario, there is emphasis on integrating the subject with other subjects.

4.3.2.2 Enablers of Retention

There are connections between subjects; emphasis on elaborate ways of representing the subject; and application of concepts to different situations that cater for the indicators of perceived utility, elaboration and rehearsal.

4.3.2.3 Barriers to Retention

There seems to be few opportunities for the teacher to assist learners by looking at the concept in elaborate ways. Not much has been presented to address the indicator of attention and elaboration, and the curriculum is rather quiet on the use of technologies to mediate learning and cater for different learning styles.

4.3.3 The South African Curriculum

The South African curriculum was viewed through an analysis of the Grade 8 Platinum Mathematics textbook (Bowie et al. (ND) that is considered CAPS compliant and follows the official sequencing and pacing. The themes that guided the analysis of the textbook verified whether it shows hierarchy, sequencing, connections and how it addresses the indicators of retention.

The textbook arranges the concepts from simple to complex. At Grade 8, the topics start with whole numbers, move to algebraic expressions at the beginning of Term 2, fractions and concepts of the Pythagoras theorem in Term 3, and finally, functions and relationships in Term 4. The topics are well sequenced according to complexity, and within the topics there is a clear hierarchy, for example, the fractions topics are arranged in the following order that shows a careful sequence:

1. Understand the fractions
2. Add and subtract common fractions
3. Multiply common fractions
4. Divide common fractions
5. Squares, square roots, cubes and cube roots
6. Percentages

It is clear that there is a clear sequence and hierarchy from simple to complex and known to unknown in the book. The text book also starts the topic with colourful visuals that aid understanding and offer instructions on how to solve problems. On the left is a column with mathematics ideas and connections to other topics and subjects, for example, music and baking is integrated with the topic on fractions (Figure 4-1).

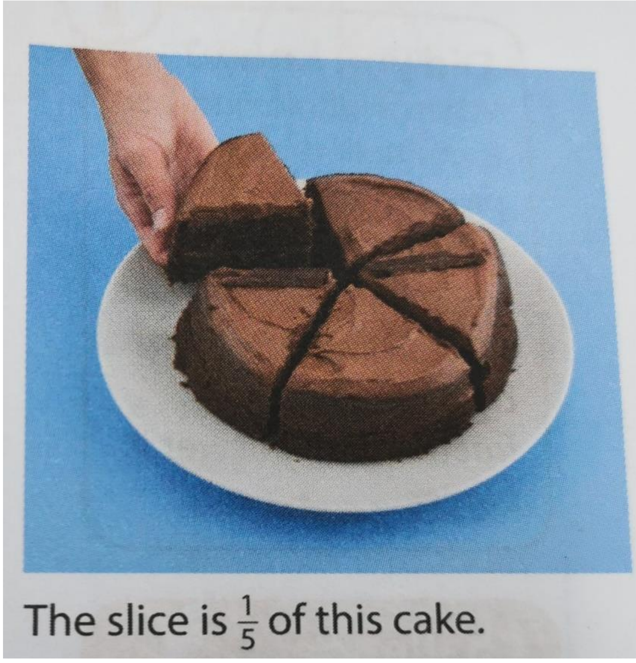

Figure 4-1 The topic on fractions is connected to real life with colourful pictures that cater for visual learning styles

Approximately 10 practice items are given per day for learners to practice the concept and two examples are provided each time to help the learners. At the end of every lesson, there is one challenge question for children who are ahead of others, and at the end of the term there is a single revision exercise to help learners prepare for exams. It must be noted that learners can do twice or even thrice as many practice activities using applications such as MyPedia.

My conclusions on the Grade 8 platinum textbook are that it addresses a variety of learning styles, lists technology that can be used and also seeks to connect the subject to real life situations and concrete objects. With such a textbook, one is forced to ask what is going wrong with the teaching of mathematics in South Africa. The answer lies in the practical implementation of the policies and recommendations of the textbook. In the actual learner books, I did not see a single question that was at an application and problem solving level. Again, none of the studied exercise books reflected the challenge question that is supposed to be used to enhance mental effort. By Term 3, all the revision exercises at the end of the term's work were done after learners had written their end of term tests, and they were not marked. What I noticed was that although the revision exercises where not marked, in the sample of two of the really struggling learners who were getting very low marks in the daily exercises, all the answers were not only correct, but similar to the answers at the end of the textbook. While feedback is important and encourages the double loop, when it is provided as answers at the end of the book, it encourages cheating and leaves the teacher with the assumption that all learners understand the concept, which would be incorrect. It follows, therefore, that the teacher has to do all the marking for an average of 40 learners, each day marking around 600 items per subject, assuming all learners write 10 items in class and 5 for homework. Marking becomes a challenge, which explains why most of the books and work is not marked. Added to this, the textbook caters for average and excelling learners, with single activities of 10 items at each level. Applications such as Mathletics provide several activities of 10–20 items that are elaborate and adaptively presented for each level. Seven topics, each with approximately seven different activities for each term are provided, and in between, there seems to be no opportunity for the teacher to move back and strengthen conceptual understanding. I also noted that in the learner books, many of the suggested textbook activities that are meant to apply concepts are skipped. In the observed Grade 8 exercise books, the first three activities on exponents were not reflected in learner books, and the topic on functions and relationships was skipped. During Term 2, the teacher did not start from these topics but went on to the second activity on the new topic on algebraic expressions. As expected, leaners did not do well. Many topics were skipped, and it is my view that teachers were rushing to catch up with the pace of the curriculum. The major barriers to implementing the progressive activities in the textbooks and curriculum seems to be time for marking, for finishing topics, for planning and for individualising teaching. There is not enough time. The literature on ICT tools and how it addresses some of these issues confirms that it has the potential to enhance mathematics learning in a way that promotes the retention of concepts.

4.3.3.1 The Nature of South African Mathematics

The South African textbook is not an inferior resource for teaching mathematics. The textbook shows sequence, hierarchy and connections that are also emphasised in the CAPS documents. The colourful pictures and connections to real life situations caters for a variety of learning styles. What it lacks, like most textbooks, are interactivity, immediate feedback, multiplicity of activity and multiple representations, all of which can best be afforded by ICTs. The connections are apparent, but in relative terms are insufficient compared to the Finnish approach.

4.3.3.2 *Enablers of Retention and Barriers to Retention*

The emphasis on ICT inclusion in the White Paper (DoE, 2004) and emphasis on the application of concepts indicate the desire to ensure concepts are retained. Arguably, the greatest threat to retention is the detailed and prescribed pacing of the South African curriculum that denies both learners and teachers an opportunity to elaborate on, rehearse, connect and use concepts in different contexts. The practice of making black and white copies of workbooks defeats the purpose of representing concepts in colour and multiple formats to cater for varied learning styles.

4.3.4 Comparison of Curriculums

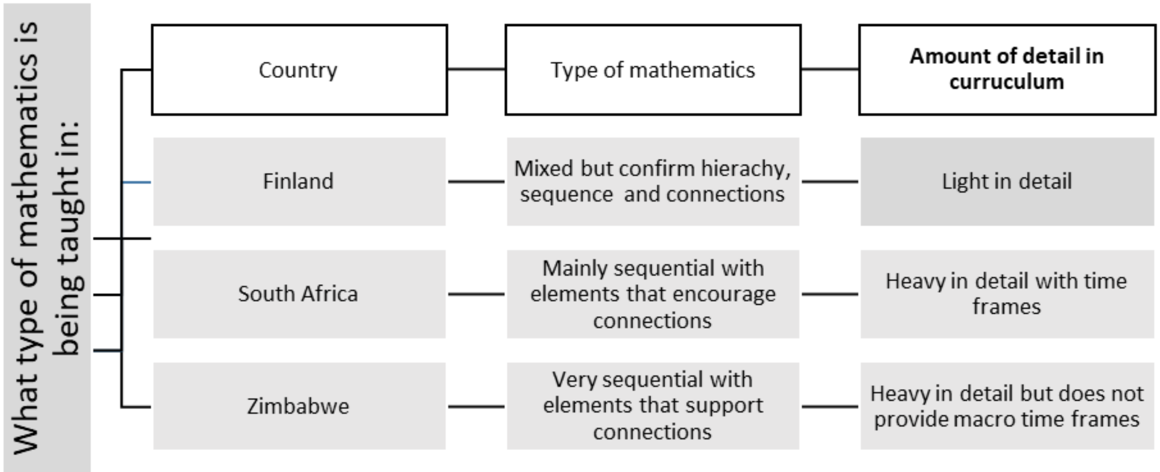

Figure 4-2 The type of mathematics taught in the different countries under study

Figure 4-2 shows how the South African curriculum fares in comparison to the curriculums in the selected countries. In terms of sequencing, hierarchy and connections, the curriculum fares well in comparison to the Zimbabwean curriculum and is far more detailed than both the Finnish and Zimbabwean curriculums. The South African curriculum even prescribes pacing, which makes it possible to complete all topics within the prescribed time period. Each topic and concept is allocated specific time frames, which I think is the major problem with South African mathematics. Prescription presupposes that all learners are the same and will learn at the same pace, which is incorrect. It puts pressure on the teachers to finish topics without ensuring that learners have understood, retained or even applied the concepts, which eventually affects their ability to retain concepts. In the exercise books studied in this research, it was apparent that while trying to keep up with the pacing, teachers skipped some activities and topics, and in many instances only gave learners a single exposure to a concept. Learners taught at this surface level will struggle in delayed tests. On the other hand, teachers in Finland, and to a lesser extent, in Zimbabwe are not under pressure to teach a certain number of topics in given time period, and so, do not have to skip any topics in order to catch up with the prescribed pacing.

From the review of textbooks and the reviewed curriculum, the mathematics taught in South Africa, although heavy in detail and pacing, can be described as being hierarchical, connected and sequential. The study of lesson plans and similar documents in the pedagogical section further established that this official view is not reflected in teachers' practical understanding of mathematics. In spite of the categories they are grouped under, the data sources that described the nature of mathematics are highlighted in Figure 4-3.

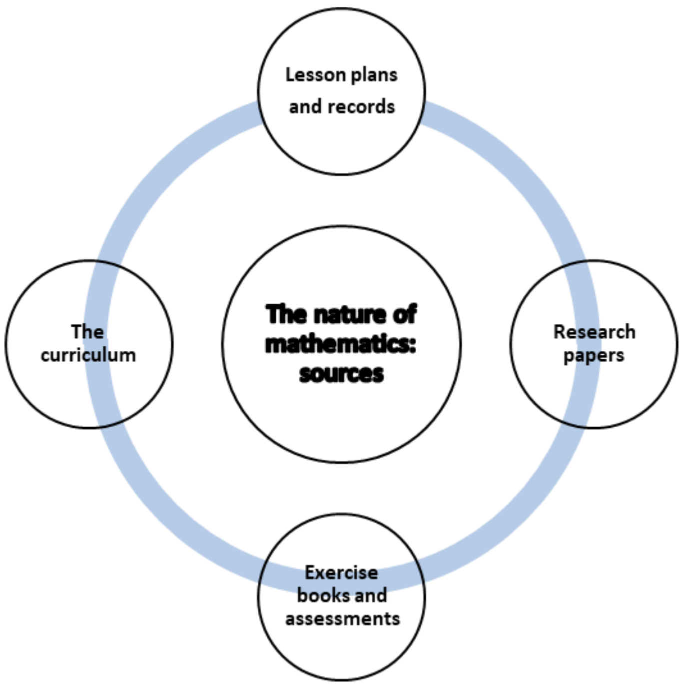

Figure 4-3 The data sources that revealed the nature of mathematics

It was essential to understand the nature of mathematics taught in different countries as it has a direct bearing on how the subject is taught, which tools are used, how the subject is paced, as well as the emphasis on content and other accompanying practices, as represented above, which all together helped to answer the research question. Besides influencing the national curriculum, the understanding of the nature of mathematics should have an impact on the tools used as well as assessments.

4.3.5 Research Papers Analysed

4.3.5.1 Introduction

Papers that straddle the four low-level categories or exclusively focussed on any of the categories were analysed. Papers from Finland, the USA and other countries were analysed. More focus was placed on the South African experience. It should be noted that very little literature was found in Africa, especially in the selected countries, on the category of ICT tools. In many instances, in the absence of the required papers, inferences were drawn from the available documents such as the curriculum, lesson plans and exercise books. Very few papers perfectly fit the requirements of this research, which justified the reinterpretation of the papers.

Research papers evaluated the nature of mathematics, retention, ICT and pedagogy sought to establish within each of these research papers, practices and strategies that had a likely impact on the indicators of retention. The research was not limited to the findings of the papers but to the theories found in the papers that formed the basis of the research.

Research paper were mainly studied to refine the categories to reach higher forms of theoretical saturation. Table 4-4 summarises the reviewed research papers.

Table 4-4 Summary of reviewed research papers

Authors	Category	Origin
Venkat and Spaull (2015)	Nature of mathematics; pedagogy	South Africa
Mathomo (2006)	ICT; retention	South Africa
Deterding, Sicart, Nacke, O'Hara, & Dixon (2011)	ICT; gamification	Canada
Choi and Johnson (2005)	ICT; video-based instruction	USA
Martio (2009)	ICT; calculators	Finland
Kilic (2013)	ICT; iPad	USA
Kaur, Koval and Chaney (2017)	ICT; iPad	USA
MyPedia	ICT; application review	South Africa
Clarke and Svanaes (2014)	Tablets	United Kingdom

4.3.5.2 South Africa

From South Africa, I selected a paper written by Venkat and Spaull (2015) on primary teachers' mathematical knowledge in South Africa and another by Mathomo (2006) that dealt with the use of educational technology in the teaching of mathematics.

Venkat and Spaull's (2015) paper provided invaluable data on the categories of retention pedagogy and the nature of South African mathematics. The paper was also selected because it promised to uncover the exact nature of problems in mathematics education in South Africa.

In their study on primary teachers' mathematical knowledge in South Africa, Venkat and Spaull, (2015) agree with pertinent observations made by (Ma, 1999) when they say, "Primary school teachers should, at the most basic level, have mastery of the content knowledge that they are required to teach" (Venkat & Spaull, 2015, p.8). The research, however, uncovered that from a nationally representative sample of mathematics teachers, 79% of Grade 6 teachers showed content knowledge levels below the Grade 6/7 band, and that good teachers are inequitably distributed (Hungi, et *al*). If this is the current situation in South Africa, it would be very difficult to introduce a system that allows teachers to move up with their learners for a number of years. The research also noted that a variety of frameworks and methodologies have all reached the same agreement on the very low and highly unequal performance of South African students (Venkat & Spaull, 2015). What tools and practices are well performing schools using to experience success?

Venkat and Spaull's (2015) research also showed that teachers lack fundamental knowledge in mathematics. In a rural school where ICT were used, that lack of fundamentals was reflected in the use of ICT for rote learning. Without an alternative learning programme, learners were at the mercy of the incompetent teacher who himself was no better than the students he taught. The instructional affordance of ICT and its ability to transfer learning to learners has the potential to level the playing field for learners who are at the mercy of such teachers. Can teachers who lack mastery in the subject they teach know how to teach the subject and what goals to focus on? Any ICT tool that such teachers use should, therefore, be more than just an aid to teaching, and be a guide, an associate, a resource and to a great extent a 'mentor' to the teacher. Although it appears that a lot of time is allocated to mathematics, very little of it is used productively because incapable teachers find it difficult to make conceptual or disciplinary connections that aid understanding and retention.

Venkat and Spaull (2015) also argued that teachers' poor conceptual knowledge impacts learner performance. This was clearly reflected in the number of skipped topics and activities, as well as in mathematics problems that were incorrectly marked. By just looking at a few memos of two tasks that were analysed more deeply, I discovered that about five of the first 20 questions had wrong answers. It is a pity that the research focussed more on documents, but I assumed that the writing of memos was either difficult or a time consuming activity. An ideal ICT tool should make provision of feedback task easier and faster. Marking books ensures learners have understood concepts and influences retention levels. An incapable teacher cannot explain and simplify concepts, resulting in learners failing to understand the concept, and concepts that are not understood are not retained.

While the need for an overt curriculum is understandable to assist teachers who lack content knowledge and to ensure that all learners in the country cover the same topics, such a curriculum in the hands of a non-creative teacher will not be contextualised or reorganised to build on interdisciplinary and specific connections that enhance the retention of concepts (Venkat & Spaull, 2015). A look at the exercise books also showed that teachers were moving quickly at the pace of the curriculum, and sometimes only a single activity was done before moving to the next topic. Considering that understanding, application and the indicators of retention all aid better retention, it is clear that a wrongly used overt curriculum is arguably one of the greatest barriers to the retention of concepts. An overt curriculum could also be a good thing in a country where teachers are often absent, allowing substitute teachers to continue from where the previous teacher ended. In 2012, the average absentee record per year in the Southern African Development Community (SADC) region was nine days per teacher. The average for South Africa was 19 days of absence per teacher, translating to 7 448 000 days of lost teaching for the 392 000 South African teachers employed at that time (News 24)

While proponents of an overt curriculum might list its benefits where learners write common tests, it might compel teachers to teach for tests rather than for understanding. Again, issues of equity and fairness are ignored if learners who are different, come from different backgrounds and are moving at different paces are forced to write similar tests. Such an approach helps the bureaucratic system and maybe the teachers to tick policy boxes, but it does not help learners in any way. It would not be fair for the schooling system to administer common examinations to learners who are operating at different levels. It would be better for learners to learn fewer topics and learn them well, than cover a syllabus they do not understand. Venkat and Spaull (2015) also raised their concerns on sequencing and pacing. In my view, the current pacing and sequencing removes teacher autonomy to ensure understanding, retention and knowledge application. It also removes important practices like debriefing, elaboration and practice. Sequencing and pacing cannot support differentiated learning based on variations in the ZAD of learners.

According to this research, the biggest problem with education in South Africa is the low number of teachers with desirable pedagogical and content knowledge. “Only 32% of South African Grade 6 teachers showed desirable levels of mathematics knowledge, Kenya (90% of teachers), Zimbabwe (76% of teachers) and Swaziland (55% of teachers)” (Hungi *et al.*, 2011). It would seem that content knowledge, more than anything else, has a great impact, if these countries’ performance is to be compared. However, it is possible for teachers who have excellent content knowledge to find a way to make their lessons interesting and in the process allow learners to understand and be motivated to work independently in the subject.

Although Taylor and Taylor (2013) provided a framework linked with topic strands rather than hierarchical levels of mathematics, the emphasis on hierarchical mathematics seems to hold traction with Ma (1999) who also argued that primary school teachers need a profound understanding of fundamental mathematics. This is even more true considering that learners who start with a sound grounding of mathematical concepts, considering it is hierarchical, perform exponentially better than their counterparts. Teachers must be aware of connections between concepts and of the progression of key ideas that allow for a flexibility of movements between representations and ideas related to them. It cannot be overemphasised that the role of a good teacher is to make connections between ideas; allow for movement between concepts and their representations; simplify concepts leading to understanding; and show an awareness of connections, of learners’ prior knowledge and of real life opportunities for application.

According to Adler and Venkat (2012) and Adler and Venkat (2014), South African teaching is disconnected at all levels of the South African schooling system. This is also evident in the lack of connections between concepts, as evidenced by the lesson plans, between mathematics exercises and between subjects. Subject teaching removes subject integration and utility of knowledge from one subject to another and would not be beneficial in the foundation phase. In a comparison, in countries such as Finland, Zimbabwe and Kenya, it was found that most foundation phase teachers move with their children from Grade 1 to 3, from Grade 4 to 5 and from Grade 6 to 7 in primary school. This allows teachers to make connections over at least two years of a learner’s life. Again, with the exception of South Africa, teachers in Finnish, Kenyan and

Zimbabwean school systems are class rather than subject teachers. This allows them to make grade connections and subject connections.

There are gaps at common content knowledge (Venkat & Spaull, 2015). I posit that gaps are a result of the disconnections listed above. The gaps, that also affect understanding and retention, are also a direct result of prescribed pacing and sequencing that does not cater for the individual differences among learners. The gaps get wider each time because, as discovered in this research, most teachers lost learner assessment records for students taught in 2018. No previous records of learners were in the files of the new teacher, implying that important knowledge that could have been used to help close gaps was not used. Record keeping as an important function of an ICT tool to aid retention cannot be overemphasised.

Venkat and Spaull (2015) questioned whether gaps at this level raise questions whether attention to advanced mathematics is an "… immediate priority in the South African teacher education landscape in spite of advocacy in the international literature" (p. 10). I have to agree with the researchers because a firm foundation is a prerequisite for learners to move on to new levels of abstraction. Could a prescriptive curriculum be the reason why learners are not doing well? Gaps signify that learners should be exposed to foundational mathematics before they are exposed to more challenging mathematics. How can a learner who does not understand number sense be exposed to algebraic equations? Start small, but start well. Make sure that the concepts learnt are learnt well. Practice and rehearsal is important, and research showed the immense potential of ICT in assisting with this process (Baddeley, 1992). It is important to start and strengthen the basics, and the curriculum should focus more on foundational mathematics and build upwards. At the moment, especially in mathematics, it seems that South Africa is building from the top.

Most teachers (79%) teaching Grade 6 had content knowledge levels below Grade 6, and 62% of Grade 6 teachers had Grade 4 or 5 level content knowledge (Venkat & Spaull, 2015). It is my argument that successful mathematics teachers, especially at lower levels, should be competent at a lower and a higher grade than what they are teaching in order for them to make connections with prior learning and to provide a 'hinge' for future learning. Not only that, foundational teachers should have wide subject knowledge to make horizontal connections with other subjects and vertical connections within the subject.

It is important to build a solid foundation for extensive attention to Grades 6 and 7 content (Venkat & Spaull, 2015)). This also signifies the importance of teaching for retention, especially in the lower classes, and having a single teacher in primary education who is a master at seeing and taking advantage of connections.

The competent teacher should therefore consider doing the following:

1. Teaching from simple to complex
2. Teaching from concrete to abstract
3. Teaching from known to unknown
4. Verifying baseline knowledge of learners
5. Making and using connections in their teaching

The above practices require a teacher who carefully plans and reflects, not only for the average learner in the class, but for each individual learner in order for them to build a conceptual understanding based on a firm foundational background. Again, a look at the lesson plans evaluated in this research indicate that none of the lesson plans had been evaluated, implying that possibly lesson plans are not being used to build connections and make interventions as it should. This could lead to the following difficulties:

1. Time for planning and reflection
2. Difficulties to plan for each individual learner
3. Difficulties to establish the baseline knowledge of each learner
4. Keeping progress records for each learner
5. Tracking progress and intervention for each learner
6. Assessments to verify success of intervention for each learner

What becomes clear, therefore, is that unless the teacher has the support of no less than two assistant teachers, it will be very difficult to plan and support activities that promote understanding, and by implication, retention for each student in an average class of 40 learners. ICT tools can be used to promote this kind of learning. It is quite true that while alternatives exist, these are not very good at keeping the type of records required for making connections.

In their study on essential content knowledge and instructional strategies on teaching fractions and ratios for understanding, Lamon (2005) highlighted the following aspects to be noted: A good curriculum is well sequenced and it is the good teacher who should sequences their topics. In

Finland were the sequencing is left in the hands of the teacher, learner performance in mathematics has been good. The implications of sequencing could firstly be that a good teacher is aware of the baseline knowledge of the class as well as individual learners in the class. In other words, the sequencing of concepts should be at the level of the class and at the level of individual learners. Secondly, good teachers should be aware they must individualise learning according to the different ZAD of each learner in order for them to close the gaps for the class and for individual learners. Learning gaps happen when the concept has left a space between what the learner already knows and what they are exposed to in the new learning experience. It has to be noted that no single teacher would be able to close the gap for each learner in a class of 30 learners. The practical difficulties of catering for individual learners require ICT tools to not only assist pedagogically but also with the administrative function of maintaining performance records. Individualised learning acknowledges that each learner is starting from a different and unique step.

Missing steps or learning gaps results in learning gaps that accumulate to cause further learning difficulties later. In as much as retention grows exponentially, gaps also grow exponentially, resulting in even lower achievement in higher grades as shown by the statistics from the DoE in Grades 2, 3 and 9 (Table 1-2).

Individualised learning helps each mathematics learner to close the conceptual gaps, and in the process, promotes retention. In a scenario where a teacher is failing to plan, to connect, to keep records and to individualise learning, all of which have a bearing on retention, one is bound to ask: What is the role of ICTs in rectifying the situation?

Venkat and Spaull (2015) argued that concepts teachers struggle with affect other topics later in the child's learning life, clearly implying their view of sequenced and hierarchical mathematics. Struggling teachers skip topics, or according to the exercise books observed, teach them at a superficial level, or as discovered in the learner exercise books, only give single exposures of concepts, which are insufficient for retention. In one instance, the teacher copied the exact example from the textbook and used that as an exercise for learners to do. In many instances, topics that are skipped because teachers are not competent or comfortable to teach, act as a basis for more complex concepts thereafter. Where teachers struggle with a concept, they usually find it difficult to represent concepts in multiple formats, as seen in the learners' exercise books. ICT tools include many teaching platforms that have YouTube videos that can teach the concepts and exercises that learners can do, with the tool acting as a more capable other that not only offers immediate feedback, but guide how questions should have been tackled. Teachers who struggle with concepts should be part of a community of practice. ICT videos can be used to promote conceptual understanding and retention.

Topics that are avoided are likely to be foundational for other topics, leading to learners struggling with certain topics that teachers are not comfortable with. ICT technologies that empower teachers to teach all topics support retention. A skipped step in mathematics learning is a threat to conceptual retention. I wanted to verify the number of topics that teachers skipped in their teaching. It was alarming to note that in one class the teacher skipped the topics on addition, subtraction and division of fractions. The topics on decimal fractions, on number patterns and on square roots were skipped in Grade 8 despite the teacher having planned for them. Learners go into the next class without baseline knowledge! There must be a way to ascertain what the learners know or do not know before they go into the next grade, learn a new topic or do a new section in a topic. The Finnish scenario confirms that a good teacher can still be effective with a skeletal curriculum, while a detailed curriculum does not necessarily lead to improved results.

There is a crisis in primary school mathematics teacher content knowledge that is confirmed by the poor performance in mathematics in high school (Venkat & Spaull, 2015). The crisis in high school mathematics confirms a lack of foundational mathematics because learners were not taught in a way that promoted understanding and retention. A good ICT tool should, in a situation with an incompetent teacher, act as a teaching tool, a learning tool, a practice tool and an assessment tool. The issues raised in Venkat and Spaull's (2015) report and their possible implications on other categories are summarised in Table 4-5.

While it is tempting to say that the deficiencies in South African mathematics teaching can be remedied by the inclusion of ICT tools, Venkat and Spaull (2015) argued that fancy technology, just like a good curriculum, cannot back up a poorly designed lesson. The success of ICT tools depends on the competent teacher to plan a good lesson and decide when and where ICT tools are used. It is the teacher who is capable of setting goals for the day's lesson based on learners' prior knowledge.

Table 4-5 Impact of practices on retention and implication on ICTs

Practice	Impact on Retention	Implication for ICTs
1) Teachers who lack adequate content knowledge	Struggle with marking Behind with marking Wrong marking affects understanding and motivation	Affordance of ICT to offer immediate feedback Teaching platforms such as YouTube can explain concepts clearly
2) Concerns on sequencing and pacing	Lack of sequencing affects understanding and retention Pacing affects time allocated for elaboration, practice, and opportunities for use of concepts	ICT can be easily manipulated to scale up or down ICT affordance offer opportunities to apply knowledge
3) Lack of fundamental content knowledge	Teachers who lack fundamental knowledge cannot teach for understanding They cannot teach for retention—no elaboration and interest component; hence, encoding is negatively affected Inexperienced teachers struggle with preparation and selection of relevant teaching media	YouTube, explanations on certain programmes, and webpages such as Khan Academy can take over the role of the incompetent teacher. Both the teacher and learners have a present teacher who they can learn from ICT affordance to make lessons interesting Multimodality affordance of ICT
4) Lack of fundamental pedagogical knowledge	Teachers struggle with multiple or elaborate ways of representing mathematical ideas Absence of individualised learning pathways that connect current to prior knowledge	ICT affordance. Concepts are represented diagrammatically, symbolically and through actions
5) Disconnect at all levels	Without connections there is no elaboration, and therefore, there is reduced retention	ICT affordance of connecting concepts to virtual environments
6) There are gaps at common content knowledge	Gaps indicate lack of connections and disconnect between present and prior knowledge, which could indicate absence of baseline knowledge Some topics are not taught well and others are skipped	With ICT it is easier and faster to establish baseline knowledge. Concepts taught using ICT can be scaled up and down to close the gaps Teacher can place a block to prevent learners from proceeding to next topic before mastery of elementary topic ICT is a resource through YouTube and other platforms of teaching difficult concepts and topics to learners

4.3.5.3 The Nature of South African Mathematics

From a practical implementation of the curriculum, the way the subject is being taught is disconnected. It is not really surprising that this practical view of the subject does not support the retention of concepts. There seems to be a disconnect between the official curriculum and the curriculum ‘of the classroom’. Pacing and the quality of the teacher seem to be the main sources of this disconnect.

4.3.5.4 Enablers of Retention and Barriers to Retention

From this research it can be seen that the greatest threats to indicators of retention are teachers with poor content and pedagogical knowledge that negatively affects connections and the application of knowledge, which ultimately enhance the retention of concepts. Conceptual gaps and teachers’ low content knowledge affect both the sequencing and hierarchy of concepts, which in turn affects retention. While the South African curriculum looks fairly good on paper, research indicates that the major problems are at the implementation stage, in the classroom, by the teacher. It would appear that technology should not only be used as a learning tool, but also as a teaching tools to 'mask' the deficiencies identified by Venkat and Spaull (2015).

4.4 Retention in Education

The category retention seeks to address the following research objective and question:

Research Objective

To establish the importance of retention in mathematics education.

Research Question

What is the role of retention in mathematics education?

As has already been seen from available literature, educators who are aware of retention as a goal of education will carefully plan and sequence their lessons to cater for the goal. The category of retention was studied further to refine the information on indicators of retention mentioned in the literature section. The papers and documents under this section were evaluated on the basis of how they enhance indicators of retention and illustrate how these support hierarchical, sequential and connected mathematics as, confirmed in the first category. The findings of the first category were based on policy documents but were subjected to further scrutiny by comparing them to the actual practices in the classroom that indicate the teachers' practical view of the nature of mathematics.

The five indicators of retention that emerged from the initial low-level category of retention are:

1. Perceived utility
2. Attention
3. Elaboration
4. Rehearsal
5. Connectedness

In this category, the data collection and analysis stage was approached with both the low-level and secondary category already being available to initiate the study of all the other categories. This category was reviews again to refine it, leading to the emergence of tertiary and even quaternary higher level categories on retention. The initial low-level and emergent categories are illustrated diagrammatically in Figure 4-4–4-8.

Indicators of retention are suggestive of activities that should ordinarily result in enhanced retention of concepts. Retention is one of the two most important categories in this research (the other being ICT) and was used as a tool to evaluate how current practices and the curriculum could best be mediated by ICT tools. Based on the literature and documents studied in this section, the indicators of retention were further summarised and broken down into specific higher categories or enabling practices that describe their overarching indicator. From the literature reviewed, each of the indicators can be broken down further into more refined categories as shown in Figures 4-4–4-8:

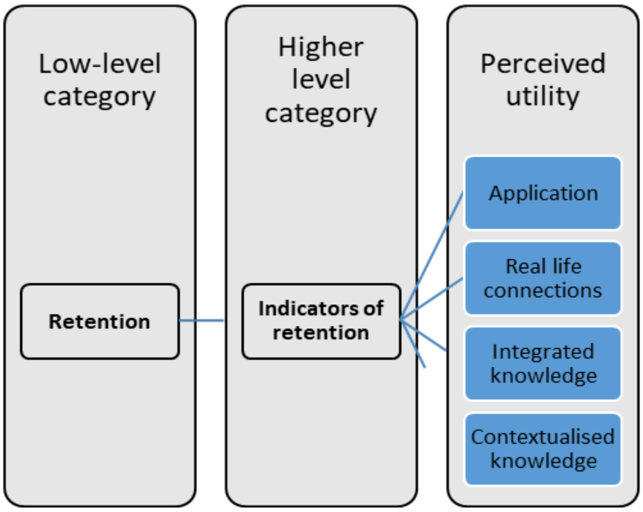

Figure 4-4 Perceived utility and emergent categories

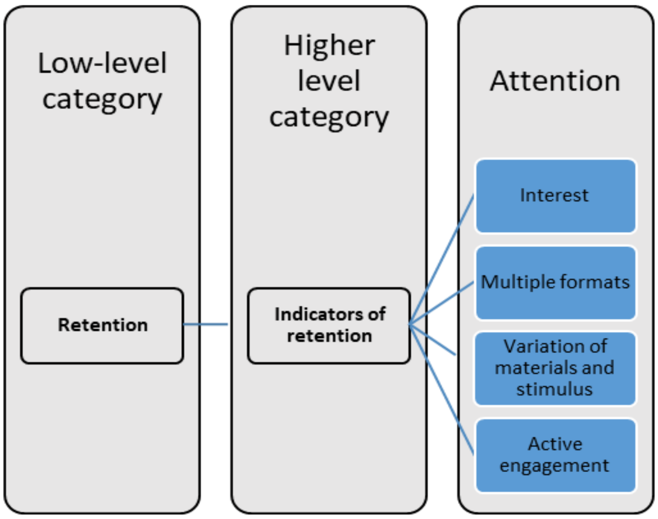

Figure 4-5 Attention and emergent categories

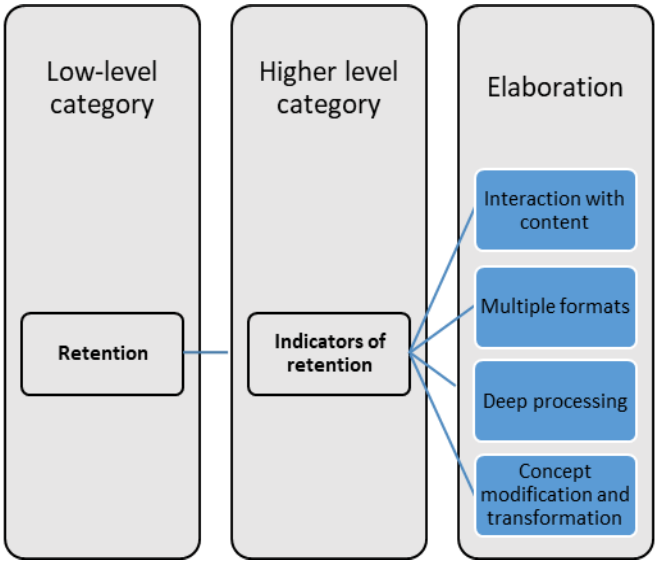

Figure 4-6 Elaboration and emergent categories

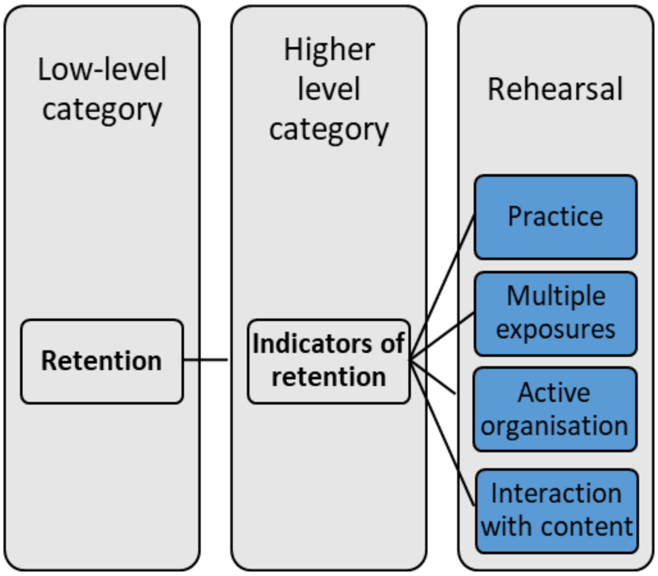

Figure 4-7 Rehearsal and emergent categories

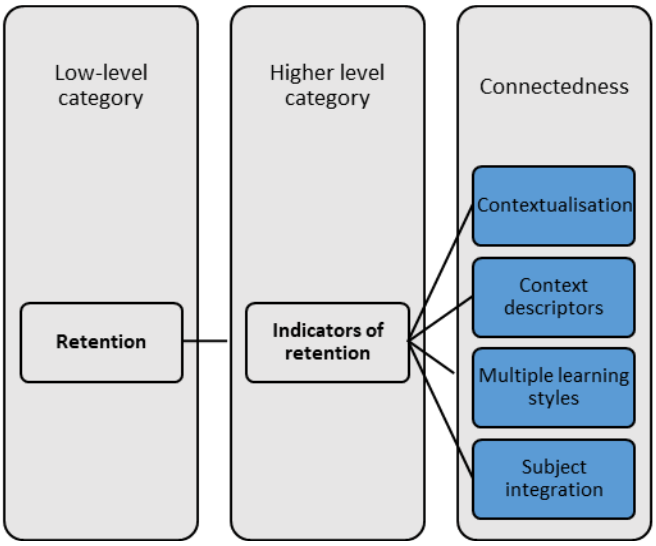

Figure 4-8 Connectedness and its emergent categories.

The secondary and tertiary categories in Figures 4-4–4-8 were further refined and authenticated through corroborative papers that were reviewed in the data collection and analysis section. All other practices and activities, such as motivation and gamification, can be categorised under one or more of the listed sub-categories and specific elements of each indicator. It is envisaged that there are other practices such as application that enhance retention, but have not been initially listed as such in the literature section under indicators of retention.

If learning is that which remains when everything has been forgotten (Neisser, 1982), it follows, therefore, that conceptual understanding not underpinned by activities that move items into the long-term memory is insufficient for the purposes of advancing further learning or aiding application. This is why research has noted that learners do not perform as well in the delayed assessments as they do in assessments soon after lessons (studied mark sheets).

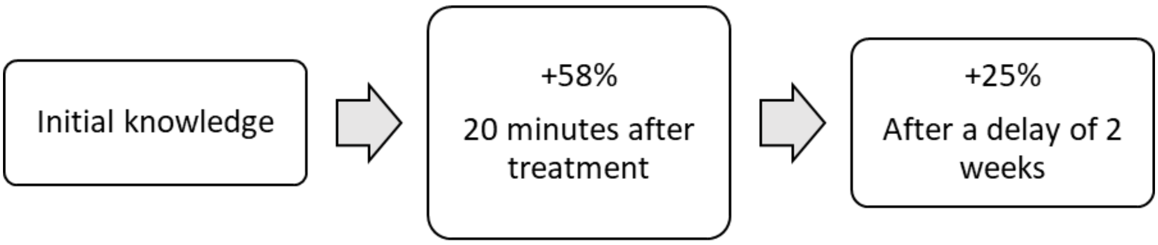

Figure 4-9 Huge gains immediately after a lesson that drop to 25% after a period of just two weeks (adapted from Murre & Dross, 2015; Craik & Lockhart, 1972)

Diagrammatically retention can be roughly represented as in Figure 4-9: There is an immediate spike in performance soon after a lesson, followed by a relative decline that is dependent on whether learners were exposed to practices that mitigate decay or support retention during the lesson. Used correctly, ICT tools should amplify the concept. Figure 4-9 indicate that immediately after lessons, there is an immediate spike in performance and understanding. This raises many questions about the correct timing of assessments that would be truly reflective of learner competency in the concept.

The retention pyramid in Figure 4-10 shows activities that promote the retention of concepts. Ranked at the top of the table are practice activities or rehearsal, teaching others, discussions and demonstrations.

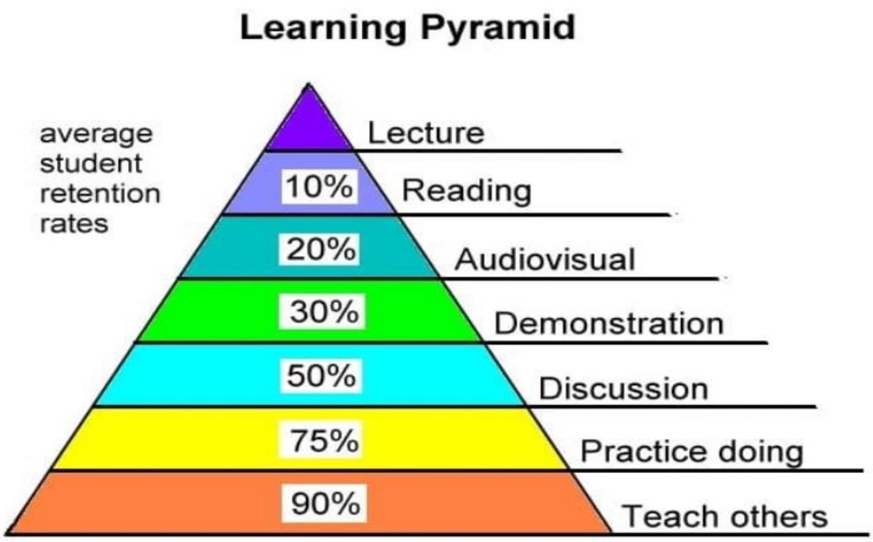

Figure 4-10 The learning retention pyramid (Source: National Training Laboratories)

Lecture methods, reading, audio visual stimulation and demonstrations, though most of them can be mediated by ICT tools, rank very low on the retention pyramid. Activities have significance when they are accompanied by opportunities to teach others, to practice, to discuss or to demonstrate, as also suggested by the indicators of retention. Again, this confirms findings that suggest that ICT stimuli that does not involve mental effort does very little to enhance retention. All the activities that rank high in impacting retention have one thing in common, they transfer the learning process to the learner.

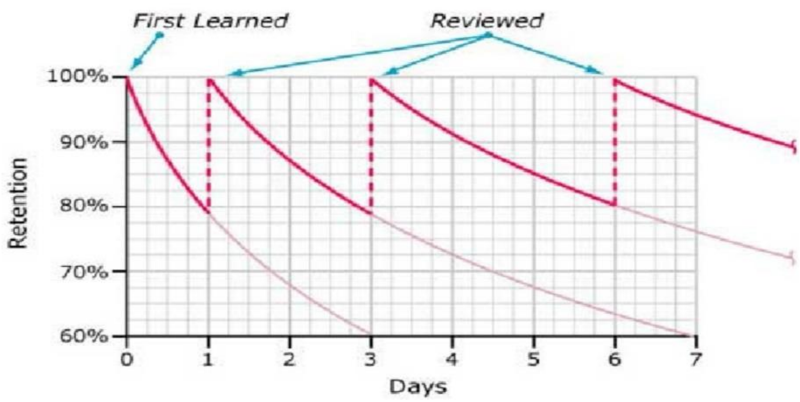

Figure 4-11 The direct correlation between retention and review (rehearsal and elaboration)

Figure 4-11 simply illustrates how practice and review of an item, either through a double loop that is supported by immediacy of feedback or spaced out assessments, have a tendency to gradually slow down the decay of concepts, with the rate of forgetfulness increasingly becoming insignificant the more learners rehearse and elaborate on a concept. This is arguably the space where ICT tools can be used optimally to assist in learning. It is argued again here that the correct use of technology should not lead to the maintenance of the concept, but through the indicators of retention should rather lead to its growth beyond the 100% initially learnt. A question on whether tests and assessments reflect merely an immediate or a sustained understanding of concepts will be briefly addressed in the section on assessment in the pedagogy section.

Drawing from literature, the category of retention has been refined and the higher level categories that emerged are shown in Table 4-6.

Table 4-6 Showing the development of retention from its low-level category into its emergent higher level categories

Low-Level Category	Secondary Categories	Tertiary Categories	Quaternary Categories	Quinary Categories	Senary Categories	Septenary Categories
Retention	Perceived utility	Application Real life Integration contextualised	Problem solving	Assessing all topics Applying all topics		
	Connectedness	Contextualisation Context descriptors Multiple learning styles Subject integration	Context descriptors Multiple formats Multiple learning styles	Baseline assessments Individualised plan	Hierarchy Integration Phase teaching Class teaching Use of data	Record keeping Conceptual levels rather than grade levels
	Attention	Interest Motivation Removal of habituation	Motivation Staying power	Multimodality	Gamification and attitudes	
	Rehearsal	Practice Multiple exposures Active organisation Interaction with content	Active engagement Self-directed activities	Spaced activities Frequent assessment Back and forth	Double loop overlearning	
	Elaboration	Content interaction Multiple formats Feedback Concept modification and transformation Deep processing	Rehearsal Concrete, enactive and symbolic forms	Learning styles according to conceptual understanding and level of child		

4.5 : **ICT Tool Usage in Mathematics Education**

The study of this category addresses the third research objective and research question, although there are many overlaps among the categories and emergent themes.

Research Objective

To establish how the use of ICTs contributes to the retention of mathematical concepts.

Research Question

Which ICT affordances enhance the retention of mathematical concepts?

Because of the large diversity of ICT tools, it was not possible to study all of them. Only the following tools and programmes were studied:

- Videos,
- Mathletics and MyPedia (The mathematics programmes were studied through reviews done by their originators. The potential biases are acknowledged.),
- Calculators,
- iPads and tablets, and to a lesser extent
- The IWB.

The papers studied for this section included De Witte, Haelermans and Rogge (2014) who studied the effectiveness of Computer Assisted Instruction (CAI) on learning; Kang (2016) who brought clarity on the frequency of practice; Deterding et al., (2011) on gamification; Kaur et al. (2017) and Kilic (2013) on the effectiveness of iPads; Gambari et al. (2017) on the effectiveness of blended learning and e-learning modes; Choi and Johnson (2005) on context-based video instruction; Chesitit (2015) on the impact of ICT integration on mathematics performance in Kenya; Martio (2009) on the use of calculators; and finally Clarke and Svanaes (2014) on the use of tablets.

The rapid changes in educational software, with many being advanced and extremely adaptive, removed the need to recommend a particular application. Rather, the study mainly focussed on broad affordances and considerations that schools should be aware of before selecting ICT tools. Detailed comparisons should be pursued in a future experimental study on the selected tools.

4.5.1 Effectiveness of a Computer-Assisted Maths Learning Programme: (De Witte, Haelermans & Rogge, 2014)

Skinner (1954), in De Witte, Haelermans and Rogge, (2014) believed that learning machines (educational technologies) enhance the learning process. De Witte, Haelermans and Rogge, (2014) named the major affordances of ITC tools as increasing possibilities for repetition as well as classroom differentiation. They also argued that the tools enhance conceptual understanding, with their major strengths being their interactive nature as well as high frequency interactions between the teacher-system-learner. De Witte, Haelermans and Rogge, (2014) identified the adaptive nature of ICT tools that makes it possible to customise both instruction and feedback, allowing learners to self-organise their learning. The biggest claim made by the authors was that educational technologies can play an important role in the democratisation of access to education, particularly to children from disadvantaged settings. The potential for ICT to assist teaching and learning, especially in South Africa where most teachers have inadequate content knowledge, requires urgent utilisation (Venkat & Spaull, 2015). Individualisation is not only beneficial for attention; it also allows learners to build their learning on the basis of their own firm ZADs. The research also highlighted that while technologies hold much potential for learning, they can easily become a source of distraction.

The paper sought to contribute to the expanding literature on educational technologies by:

1. Examining the effectiveness of an online and adaptive educational tool in learning mathematics in a secondary school;
2. Discussing the effect of computer assisted learning tools (CAI); and
3. Addressing some of the methodological concerns observed in previous researches (De Witte et al., 2014)

According to Alavi and Leidner's (2001) framework for effective technological mediation, there must be a proper integration between technologies and pedagogy. The framework supports the view of this research that without the requisite pedagogical and integrated framework, the presence of ICT tools will not automatically lead to enhanced retention of concepts.

To verify if CAI tools improved learning outcomes, De Witte, Haelermans and Rogge, (2014) estimated a regression that correlated with the intensity of use of technological tools and school attainment. Attainment, the independent variable, was measured by the outcome of school exams with the information on pre- and post-tests and the consideration of contexts. The teacher's role in the use of technology was used to do an instrumental variable analysis to verify whether the intensity of exposure to CAI tools caused higher test scores. The type of tool selected, how the tool was used in the classroom, and how the learners actually used technology were all factored in.

4.5.1.1 Results

It was determined that more exercises with the tool resulted in higher test scores, with an average of 50 exercises by learners increasing their score by 0.0035 (0.0007*50) (De Witte et al., 2014). In contrast to these results, Birgin, Bozkurt, Gurel and Duru (2015) concluded that short-term CAI implementation did not make a significant difference to student attitudes (Birgin et al., 2015). A positive attitude towards ICT should have a positive impact on self-efficacy. Other authorities such as Cener, Acun and Dimirhan (2015) disagreed and submitted that learners' prior knowledge and not their attitude leads to post-test achievement scores.

4.5.1.2 Discussion

The findings of De Witte et al. (2014) are particularly important to this research as it brings to the fore the important role of the class teacher in a technologically mediated classroom. There are direct implications to the indicators of retention, including the need to expose learners to more rehearsal opportunities and to present concepts multimodally (Mathomo, 2006). The importance of immediate feedback in self-directed learning cannot be overestimated.

The authors claimed that making learners do more exercises (practice doing) leads to higher test results and that people recall things that bring them pleasure. The gamification element in some mathematics programmes also enhance the joy and motivation to do the subject, which also enhances task time (Deterding et al., 2011). The authors further claimed that learning happens through perception and data acquired through human senses. The more senses involved, the better. As has been noted, each activity should include some form of mental effort to impact positively on retention.

Visualisation assists in better understanding shapes and figures. Although there are mental tests in the written curriculum and textbooks, at a practical level in learner books mental mathematics is absent. This could be a result of lack of preparation by the teacher, lack of time due to prescribed pacing and so on. All these problems could be remedied by using ICT to provide, mark and offer immediate feedback to daily mental problems.

According to Ertmer (2005), prior knowledge enhances performance. There has to be a connecting step or a connection between concepts and topics in order for learners to do well and yet in all the observed books and lesson plans, there was no provision to establish baseline understanding. ICT applications that have a huge store of exercises and offer immediate feedback would be greatly beneficial to support baseline assessments. Quite often the superficial achievement immediately after the lesson masks the absence of a deeper, firmer understanding that can only be built on retained concepts. Mathomo (2006) made similar claims, saying that prior knowledge is important to reach higher levels. If prior knowledge is as important as Mathomo and other authorities say, baseline assessments to verify understanding must be mandatory before any maths lesson.

Kang (2016) was of the opinion that spaced repetition promotes efficient and effective learning. Observations of the assessment programmes showed that although the plan in the term assessment plan (TAP) is to space assessments, in reality, these are left to the end of the term when they are all administered together.

Spaced out repeated encounters with the material are beneficial and these should allow a back and forth movement on a concept so that it evolves, grows and are constantly retrieved at the same time. The advantage of ICT programmes such as MyPedia and Mathletics is that they have a variety of questions and programmes that can be scaled up and down to address the same concept. It is also very easy for ICT to be used to create more tests for practice and to store records that support and act as a basis for further practice.

The administration of tests and assessments should be carefully planned for taking into consideration that spaced out practice aids retention and that massed practice leads to lowered attention and diminished retention. The fact that Finland allocates the least time for mathematics and yet achieve a lot more in terms of learner achievement can be explained by the fact that schools are linked to universities that advise them on good teaching practices that are effective, including the proper timing of assessments. If the purpose of tests and assessments is understanding and retention, the current approach of teaching and testing for marks is not helpful because there appears to be a huge disconnect between teachers' term assessment plans (TAP) that show spaced out practices during the term and the massing of assessments in learner files and books. This will have an impact on the number of topics covered per grade and per unit period. Considering the time limitations, the flipped classroom can be used to increase exposure to content mediated through the use of ICTs. Again ICTs can be used to lessen the burden of marking, setting assessment tests, keeping records and individualising learning and assessments, resulting in learners doing a lot more work and retaining concepts even better.

Hundreds of studies in cognitive and educational psychology have demonstrated that spacing out repeated encounters with the material over time produces superior long-term learning compared to repetitions that are massed together (Kang, 2016). This also includes the incorporation of tests into spaced practice to amplify the benefits. Intelligently set tests and assessments should lead to further learning through tagging concepts that are not being asked about. This goes hand in hand with my earlier proposition that assessments should also aid learning, so that even if a learner fails to answer a question, they learnt something from the question.

Spacing effect, also referred to as distributed practice, would be most effective if tests are available over time. The issue of storage of these practice items and performance records becomes an issue. Marking and prepping of these items would also be a lot of work, and time constraints when a teacher is supposed to move onto another topic becomes an issue. Setting of tests, recording performance and storage of physical stacks of assessment papers and records over time potentially creates a lot of difficulties for the teacher. Put differently, ICT works well for the facilitation of spaced out practice: Observations of assessments indicate that at most an item is practised during the term it is taught and maybe during midyear and end-of-year examinations, without being incremental in any way.

The results of the study showed that in an immediate test, those who mass practice do better. In a delayed test, 4 weeks later, those who space out practice (10–20% of time period) do better (Kang, 2016). The question to ask now is how soon after practice are we going to write the test. The answer? Give revision tests all the time, for last week's work, last month's, last year's and, the last two years'. Such a store of tests can better be kept with an ICT tool.

Just as has been confirmed by Figure 4-11, repeating an item (or rehearsing), potentially reminds a learner of its existence, which prompts retrieving the previous presentation of the item; a process that enhances memory. Massed practice skips the process of retrieval because the item has just been presented. This is the major disadvantage of assessments that are administered soon after the lesson. The second theory on spaced out practice emphasises the learning context that is the physical and mental surroundings during the learning or study episode (Glenberg, 1979, in De Witte et al., 2014). There are more varied contexts with spaced out practice that will all serve as effective cues for subsequent retrieval of the item (Glenberg, 1979, in De Witte et al., 2014). Both theories are best facilitated by ICT tools that act as a store for assessments as well as provide authentic environments that act as cues during later retrieval.

The third theory is called the deficient processing of massed repetitions, which implies that if the current item is the same as another one that has just been presented, redundancy reduces attention (Magliero, 1983). This is the reason why overlearning activities have to be approached with caution lest they lead to rote and a reduction of attention. One of the tasks I studied in this research gives a clear example of this: The Grade 8 teacher asked the question:

$8n + 9 = 25$, therefore, the value of n is __.

There was a similar question in the learner books. It would be expected that on seeing the problem for the second or third time, the learners already knew the answer and did not necessarily focus on understanding and retaining the concept. In my observations, a variety of questions on fractions at Grade 6 level had the same structure and format, which does not encourage much mental effort because the learner can do the first problem and can easily do all of them without paying much attention.

There is a difference between retaining how to do something and retaining the answer. The latter is rote and not beneficial. To promote conceptual retention, the algebraic equation could have been asked in a variety of ways and represented in a variety of formats, which could be done with ICT programmes such as Mathletics. Teachers are limited in how they can present and ask concepts, and the ordinary teacher with an average class of 40 learners, a load of 24 hours per week and limited pedagogical and content knowledge (Venkat & Spaull, 2007) cannot do that. They do not have enough time.

Remembering facts, such as time tables and a transition from calculation to direct memory retrieval of the answer, allows for more efficient problem solving, (Siegler, 1988). Siegler, (1988) listed facts, formulas and skills as things that require recall. I prefer to use the term 'retention' in this research because it implies that the recalled item has been an understood item.

Practice promotes not only accurate recall of multiplication facts in children (Rea & Modigliani, 1985), but also faster retrieval of target responses further confirming the importance of practice in enhancing retention. The following observations were made: Testing, which is more beneficial than rereading, if added to spacing, will result in spaced retrieval practice (Rea & Modigliani, 1985), which is beneficial for retention. Testing and spaced practice got the highest utility ratings of all the strategies.

Although acquiring and retaining knowledge matters in education, a more crucial objective is transfer, the ability to use what was learnt to answer new questions or solve new problems. In the learner books I studied, I did not see any evidence of conceptual application. This could be as a result of teachers not having time to do so or failing to create contexts through which concepts taught could be applied. The term ‘application’ has a rather broad definition that includes all higher order activities from and beyond application itself in the Blooms Taxonomy (Bloom, 1956).

Mere remembering of content is rote learning, focussed on the past, and yet, on the contrary, meaningful learning involves transfer and orients towards the future (Mayer, 2002). For this to happen, all lessons should have a future function or utility, including being given the same attention during assessments and testing. Again, real learning is not limited to getting an answer, learners can easily that get through calculators or Google, but involves a transfer of such content through a process that require some form of mental effort. Mind wondering (when learners tend to lose concentration) occurs more often in blocked practice than in interleaved practice. Spacing, varying and scaling up questions so that they are not predictable or the responses recitable will enhance the value of the learning experiences through ICT tools.

While a complete overhaul of teaching may be difficult in the short term, modifications can be made on homework where topics and activities can be spaced and mixed for optimal benefit. Again, rather than cramming, which is massed practice, teachers can present the same thing on different days, in different contexts, using different strategies to improve retention, and where possible, using varying media (ICT to class teaching).

“Educators frequently face serious problems concerning student’s engagement and knowledge retention” (Putz, Schmidt-Kraepelin, Treiblmaier & Sunyaev, 2018). Research has shown the advantages of gamification in keeping learners engaged and on task (Deterding, Sicart, Nacke, O’Hara, & Dixon, 2011). Research has also shown that ICT tools tend to transfer ownership of learning to the child, which enhances engagement and participation in activities.

4.5.1.3 Enablers of Retention

De Witte et al. (2014) addressed and supported all the indicators of retention and also added the following pertinent suggestions: Gamification allows learners to remember things that bring them joy; spacing out of tests is very important for retention; physical and mental surroundings can be used to act as cues for future retrieval; and lastly, transfer of knowledge to new contexts slows down forgetfulness.

The next paper I review mainly focussed on gamification.

4.5.2 Gamification: Deterding et al., 2011

Gamification can be defined as "… the use of game design elements in non-game contexts" (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011, p. 9). This approach applies game design elements to non-game contexts (Hamari & Keronen, 2017) and takes advantage of the growing passion for games (Thiebes, Lins, Basten, 2014), making the approach a relevant context for today's learners. Dicheva, Dichev, & Angelova, (2015) claimed that gamification leads to an improvement of memorisation, skills such as problem solving, collaboration and communication. From this, it can be concluded that the benefits of gamification include an increase in student motivation and attention to the task. Although it would be good to establish the effects of gamification on short- and long-term memory through a longitudinal study, the results also showed that gamification increases students' outcomes on criteria for testing.

The question now is which tools, how long, and what are the long-term effects of gamification on learners who are accustomed to learn that way? It would also be very important to establish if the gamification of learning would not have a long-term detrimental impact on subjects and topics that require a different teaching approach. Looking at the Finnish approach where learners are doing well, the rationale behind gamification are not necessarily the games, but rather, the carefully planned activities that are interesting and engaging.

Popular game designs include points, badges, leader boards, competition, immediate feedback and time constraints (Deterding et al., 2011). All these factors, maybe with the exception of immediate feedback, assist in scaling up motivation and attention to the task. Immediate feedback is important in that learners can reflect on performance and link it to the feedback, especially for items they would have gotten wrong, creating a double loop on the concept. The concept is as a matter of necessity, in simple terms, studied twice, a process that promotes retention. Gamification motivates children to participate and engage themselves more intensely, and it is structured to drive educational goals and application of knowledge outside of the game context (Moore-Russo, Kristi & Sara, 2017)

The research notes that memory retention is about 58% of total knowledge after 20 minutes, and after two weeks, it drops down to about 25% (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011). Gamification used in marketing and education to encourage certain behaviour tends to motivate learners as it promotes the broadening of teaching methodologies, which is beneficial for the reduction of habituation, which ultimately negatively impacts on retention.

Deterding et al. (2011) conducted an experiment on two groups, one that learnt the topic of sustainable transport via gamification and the other that used traditional approaches. The results of the research indicated that the gamified group achieved higher scores in knowledge than the non-gamified in the short term. There are obvious advantages in the short term. The research used a pre-test and random selection of cohorts to receive treatment. The workshop was 6 hours long; it was acknowledged that 6 hours is a short time to make any conclusions and generalisations on the research. Gamified workshops included motivational affordances such as competition, leader boards, badges, time constraints, storytelling, immediate feedback, rewards, clear goals and social interaction. Competition among groups encouraged collaboration which ranks very high on the retention table (Figure 4-10).

4.5.2.1 Results

The research found that in terms of performance in the short term, there was no significant results. Thus if the goal is simply to teach for understanding, many good teachers can do that using a variety of teaching media. The challenge comes where that understanding has to be sustained. However, the gamified group slightly outperformed the non-gamified group, which is probably understandable considering that the intervention was only applied over a very short time. A longer period would probably have produced a very different set of results.

4.5.2.2 Enablers of Retention

The results of the study showed that gamification motivates and increases attention and on task time. These are all very important components of a flipped classroom. The approach also increased the joy of learning, and research has already indicated that learners remember things that bring them joy (Deterding, Sicart, Nacke, O'Hara, & Dixon (2011). Gamified contexts with feedback creates a double loop that increases the number of times an item is studied. This has a lot of implications for the way teachers are currently approaching marking. The books I evaluated were poorly marked, and almost all of them were deficient in timeous, meaningful feedback. Learners were allowed to move on to a new topic without reengaging with concepts that form the basis of new lessons. This denies the learners the opportunity to study the item twice. In informal discussions I had with teachers, the main barriers to giving immediate feedback were that teachers did not have time for marking and that they felt the curriculum trackers did not provide enough time for revision and verification of baseline understanding.

4.5.3 SOLO Taxonomy: Mathomo (2006)

The next research studied was conducted by Mathomo (2006) who used a SOLO taxonomy. Important aspects that emerged in the research include that prior knowledge is important for reaching higher levels, which is the transfer of knowledge from and beyond application on the Blooms Taxonomy (Blooms, 1956). Also noted in the research is that drill and practice are one of the basic roles of ICTs, which Mathomo believed had a detrimental effect on learners. He had a problem with what is practised and how it is practised, not with the practice per se.

Mathomo (2006) claimed that learners in Limpopo are struggling because their teaching is centred on memorisation. It has to be noted that while memorisation relates to the same 'stagnant concept', retention is more suited to a growing, connected and elaborate concept. Literature has also shown that surface rehearsal on its own is not beneficial to children (Craik & Lockhart, 1972). To begin with, learners are not all the same and would not all necessarily benefit from ICT aided practice.

Mathomo stated that ICT cater for different learning styles that eventually impacts positively on retention. His findings did not support my research's assertion that it is not the availability of ICTs but rather their utilisation that determines their success in supporting retention.

The repetitive drill and practice for which the tools were used actually disadvantaged Hispanics (Mathomo, 2006). At face value, the statement does not uncover the underlying factors that gave this result, which could include socio-economic factors that affect the distribution of teachers to different areas. A study by Venkat and Spaull (2015) confirmed the unequal distribution of good teachers in South Africa, which could be the case in Mathomo's reference. The fact that Mathomo explained that most teachers are not trained in ICT pedagogical contexts implies that before schools embark on an ambitious drive to invest in ICT tools, a lot of groundwork, including teacher training, must be done.

Mathomo (2006) argued that mathematics should be arranged in a way that moves concepts from the concrete to the abstract. The nature of mathematics itself as seen from the curriculum documents confirm the general view that mathematics is sequential, hierarchical and connected. In between concrete mathematics and its pure abstract forms, the ICT tools can be used to provided simulated concrete contexts in preparation for abstraction. The studied lesson plans, and especially learner books, illustrated the difficulties teachers have with this.

Gamified contexts provide greater motivation for learners to move to the next level if they get leader badges and other rewards for that. The teachers hardly put any stickers in any of the studied learners' books, except for Grade 3 books. Comments in the books included "What is this?", "See me" and several crosses by the teacher's red pen. I even saw a comment that read "dirty work" in a mathematics books: The learner's responses were correct and they had demonstrated their understanding of addition at Grade 3, but because their presentation was not excellent, the teacher decided not to focus on the conceptual understanding but rather on the way the learner had presented his work. This hardly motivates the learner to want to learn more mathematics. If anything, such comments discourage learners from wanting to practice mathematics more at home or at school. The gamified affordances of ICT tools and rewards makes it possible for learners to accept feedback without personalising it. The tool only focuses on conceptual understanding and in the process assumes the role of a 'non-judgemental tutor' or better still 'the encouraging tutor' who creates a space for learners to do more problems and get motivated and rewarded in the process.

4.5.3.1 Enablers of Retention

Learner-centred activities that encourage learners to teach each other or collaborate positively impact attention and perceived utility of concepts, while the teacher's implied role is that of a facilitator. Secondly, teachers must prepare colourful media that caters for a variety of learning styles. While many teachers can actually do that, it places a lot of pressure on the teacher to prepare stimulating resources on a daily basis. Teacher are already struggling with marking and offering meaningful feedback, even with small classes of 30 learners. ICT tools have readymade media and other resources that are readily available to cater for a variety of learning styles.

The role of ICT tools in addressing different learning styles and in moving concepts from concrete to abstract are still very important. The focus once again, is on the teacher who determines which, when and how the tool should be used. Drill only adds automaticity and speed, and is of little benefit to the retention of concepts. However, the practice of tables and bonds still has its place, provided it is preceded by understanding.

Table 4-7 Memo on impact of practices on retention, tools and pedagogical implications

Concept	Effect on Retention	Implication on ICT Mediation/Pedagogy Issues
Pleasurable exercises	More staying power, more attention	Gamification increases the joy and motivation as well as staying power
Appeal to human senses	More senses, more retention	Multimodality affordance of ICTs
Numerous exposure	Results in increased retention	Issues of time Setting the assessments
Spaced exposure, fortnightly in this case.	Frequency of tests and impact on marking and setting papers	ICT have stored papers that can be automatically marked—are they contextual? Marking affordance Immediacy of feedback
Numerous distributed exposure Lack of time for revision	Pacing and prescription leaves no time for practice and revision	Flipped classroom of iPad Immediate feedback Teaching component of certain mathematics programmes
Space out tests	Teach for understanding Practice and assessments Apply Teach again	ICT can be used to put the following into ICT A teach content function An application function A testing/practice and assessment function
Repeat item	So that it reminds cognition of its presence	ICT storage function: Laptop, PC, iPad A teacher might not be able to do that in different contexts
Vary contexts	Varying contexts assists in building more connections	ICT can create multiple virtual contexts
Transfer knowledge—orient learning to the future	Transfer enhances retention	Virtual contexts and scenarios can easily be set up using ICTs to strengthen retention
Change the tests	Changing the test removes redundancy that negatively affects retention	ICT has a store of multilevel tests and assessments

4.5.4 Effectiveness of Blended Learning and E-learning Modes: Gambari et al. (2017)

The next paper reviewed was the research conducted by Gambari et al. (2017) on the effectiveness of blended learning and e-learning. Gambari *et al*. (2017) argued that the traditional methods of teaching were and are still inadequate to cater for the different needs and learning styles of individuals in a classroom setting. They argued that modern technology that includes mobile learning, flipped classrooms, e-learning and blended learning are better placed to cater for these (Gambari et al., 2017). The other important observation that the authors made was that some learners learn faster than others, understand faster than others, and yet, these differences were not and could not be taken into consideration in a traditional classroom.

The authors defined e-learning, whose effectiveness has not yet been empirically established, as the use of electronic technology to deliver education and training applications, monitor learner performance and report their progress (Gamabri et al., 2017). Blended learning is defined as combining internet and the face-to-face physical presence of teachers and students (Gamabri et al., 2017). Both these strategies provide immediate feedback and allow learners to work at their own pace and time.

4.5.4.1 Methodology

The research adopted the quasi-experimental using pre and post-test control design to compare the traditional method, blended learning and e-learning. The dependent variable was the post-test performance of the university students in the three groups (Gamabri *et al.,* 2017) that was measured after treatment, that included, among others, self-assessment exercises.

4.5.4.2 Results

The results indicated there was an improvement in the post-tests of the three groups, but also that learners who were exposed to blended learning did better than those exposed to the traditional method (Gamabri et al., 2017). The results also showed that learners taught using blended learning rather than e-learning performed much better, with no variations between genders.

4.5.4.3 Discussion

The paper is helpful in confirming the importance of face-to-face interaction during teaching and learning. Although the time of the treatment was not long, there were indicators that blended learning rather than e-learning is preferable. The retention pyramid (Figure 4-10) also demonstrated the important function of social interaction during learning, which ranks high on the retention table. This paper, together with the limitations of ICT to cater for enactive related activities, makes it preferable to use blended rather than e-learning.

4.5.5 The Impact of ICT Integration on Mathematics Performance in Kenya: Chesitit (2015)

The research by Chesitit (2015) was a case study conducted in 2015 that sought to determine the impact of ICT integration in teaching and learning on mathematics in public schools in Kenya. The research used a purposive experimental research design, focussing on five selected schools that were identified on the basis of availability of a computer laboratory.

The results of the research indicated that ICT integration enhanced understanding of concepts and skill transfer from abstract to concrete, and vice versa, as shown in the Figure 4-12. According to the figure, ICT function more effectively through its superior iconic representation affordances that mediate concrete formats to their symbolic forms (Chesitit, 2015). A different way of looking at the same diagram would be that concepts that appear as a symbolic format for learners can be simplified to their pictorial and concrete representations. ICT tools seem to have great potential to afford the back and forth movement that is crucial for the enhancement of retention. Figure 4-12 also confirms that ICT tools require utilisation with other forms of representations, including concrete formats. The progression into completely paperless classrooms must be approached carefully, so that in the process of strengthening iconic representation, the other forms are not neglected.

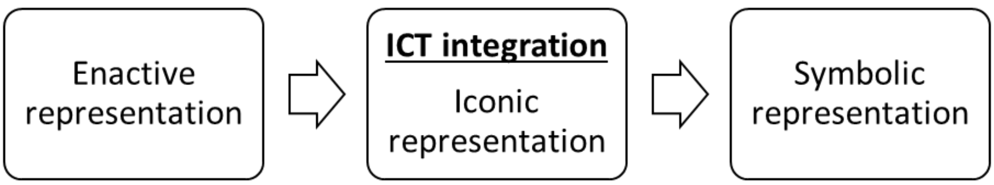

Figure 4-12 ICT integration and intellectual development process (adapted from Bandura, 1997)

Chesitit (2015) was of the view that ICT was based on how it constructs knowledge and not on its transmission. The current research focussed not only on the knowledge construction but also on how ICT tools aid in its transmission. A very important observation made was that quite often teachers jump from practice to symbolic stage, and in the process overlook the iconic stage. The ICT tools are well positioned to provide interactive iconic representations that are interactive and appeal to a variety of learning styles, as already seen.

4.5.6 Context-Based Video Instruction: Choi and Johnson (2005)

Choi and Johnson (2005) studied the effect of context-based video instruction on learning and motivation in online courses. The research purpose was to examine how video-based instruction affects learning (comprehension and retention) and motivation (attention, relevance, confidence and satisfaction). The method used was a quasi-experimental design with a post-test only instrument. Participants experienced video-based learning and traditional learning with one online module consisting of three topics. Students were then asked about their perceptions of motivation and learning. It must be noted at this juncture that though perception might have an effect on attitude towards mathematics, it is not the most accurate parameter to quantify the efficacy of ICT tools in supporting performance in mathematics. In the results, a maximum high score of understanding was 25; a higher score indicates a deeper level of understanding (Choi & Johnson, 2005).

Their research investigated the potential of context-based video instruction for enhancement of learning, with a specific focus on retention. They established that video-based instruction was more memorable than traditional approaches (Choi & Johnson, 2005). Although the retention pyramid confirms this (Figure 4-10), there is a very little difference between the two approaches. One of the issues that came up in the research paper were that ICT tools afford context-based learning using real life world contexts (Merriam & Caffarella, 1999). As has already been mentioned, these ‘real world contexts’ are not concrete in nature. They are intermediate and located between concrete mathematics and its pure form of abstraction. Pedagogical issues will arise from this observation: ICT use should ideally follow ‘tangible’ mathematics and should precede abstraction. In teaching a topic on geometry, for example, it is important for learners to have seen and touched the actual hexagon, before they see it as a real life image, and even worse, before the shape is presented at an abstract level.

Knowledge is shaped by context, culture and tools (Merriam & Caffarella, 1999). Of importance here, though outside the scope of this research, is the acknowledgement of the influence of a myriad of factors on ICT mediated learning, making it rather difficult to generalise ideal pedagogical settings. Culture is another very difficult variable to control, but a deeper understanding of this statement would seem to imply that what might work for certain learners or schools, might not work for others. Again different age groups might use different ICT tools differently; and hence, a cell phone as a learning tool would likely cause more distraction among teenagers than it would among Grade 4 learners. This could explain why so many more viral videos of mischievous activities are shot in high schools than primary schools.

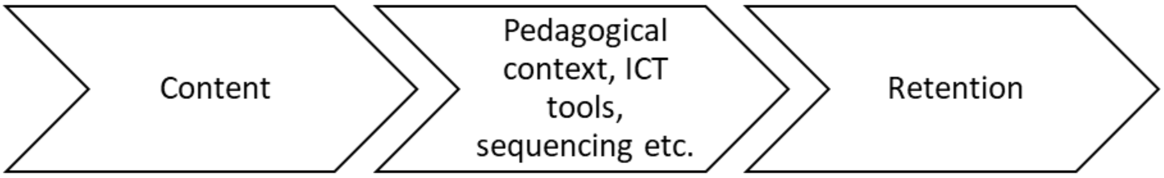

Figure 4-13 Transforming content into retainable concepts through tools and enabling practices.(Adapted from Choi and Johnson, 2005)

Figure 4-13 (Choi & Johnson, 2005) illustrates the position of ICT and the complete pedagogical setting in transforming content into retainable concepts. Context-based learning through technologies is effective for the enhancement of learners' knowledge construction, transfer or application (Jonassen, Peck & Wilson, 1999). Simulated contexts allow ICT to be used to deal with problems presented in authenticated environments with the added advantages of portability, accessibility, multimodality, safety, cost effectiveness, manipulability, and immediacy of access, making technology invaluable for learning. Videos add the interest component through enhancement of attention and motivational factors, both of which contribute positively to the retention of concepts.

4.5.6.1 Results

The research established that the critical attribute of the video are the auditory and visual symbol systems that are more beneficial when used together (Baggett, 1984). Choi and Johnson (2005) observed that a tool that caters for a variety of learning styles at the same time, would probably be more beneficial than one that only addresses a single one, and the use of multiple technologies to engage with the same topic increases cues and contexts that are beneficial for retention. When learners use technologies, they can make mental representations.

Another advantage of videos is that they expose learners to events that cannot be easily demonstrated, for example, 3D shapes and other abstract ideas, and it standardises messages and increases fidelity. Instructions that enhance understanding can be played over and over, stopped and analysed without compromising the fidelity of the original instruction or content.

A study by Salomon (1984) showed that learners do not benefit from televised learning as they are passive and are not mentally challenged. Had the videos been used to provoke and increase learners' mental effort, the results would have been different. Mental effort could include asking questions, applying the learning experience to a different scenario, writing a test or assessment, and holding a debriefing sessions after watching the video. The advantage of using ICT tools is that mental effort can be scaled up and down. It is important for learners to attain the attention, relevance, confidence and satisfaction that motivates learning.

The results of this study showed that video-based learning has not been sufficiently effective because learners were passive in the learning process and concluded that videos are more effective than text books (Choi and Johnson, 2005). However, Liebenberg, (2019) suggested that for detailed recall after a once off reading, research indicates that print books are better. Where interaction with learning content is required, eBooks appear to offer a far better learning experience. This research confirmed the importance of not over-relying on a tool for learning. A combination of textbooks and videos produces better results (Choi & Johnson, 2005). A video that allows learners to support learning with a related text-based article is therefore effective.

The results indicate that watching and discussing videos increased retention. This finding is again confirmed by the retention pyramid (Figure 4-10) that shows that collaboration cannot be replaced by technology in class. Used in this manner, ICT tools act as stimuli to provoke other activities that require mental effort and collaboration. The good thing about technology is that it affords the availability of variated simulated learning contexts that can all be used to initiate and support collaboration during lessons. The retention pyramid (Figure 4-10) suggests the importance of that process and again falsifies the notion that technology can take over the role of human in education.

The video was more beneficial to people with visual and auditory learning styles because as they say, a picture is worth a thousand words, and Choi and Johnson (2005) claimed that the video sticks in the mind. To aid understanding, videos can be stopped, replayed, exported and controlled. The pause and play function allows the learner to reflect on learning and to re-listen to an instruction, something that a human teacher would probably do, but quite often using different words and language in the process, affecting the initial fidelity of the message. ICTs are better able to cater for different learning styles including the visual, kinaesthetic and auditory, something that was not done in the studied lesson plans. A study on lesson plans has already concluded that there is a deficiency in pedagogical practices from the planning stage.

Table 4-8 Paired t-Test of learners' motivation (Choi and Johnson, 2005)

Motivation	Type of Instruction	N	M	SD	T	P
Attention	Video B I Text B I	16 16	20,38 17,44	1,82 4,00	2,66	,020*
Relevance	Video B I Text B I	16 16	16,56 16,25	1,31 0,98	0,543	,595
Confidence	Video B I Text B I	16 16	15,94 15,50	1,48 1,79	0,768	,455
Satisfaction	Video B I Text B I	16 16	15,25 13,94	1,84 3,02	1, 892	,078

NB: Maximum higher score of attention = 25. Maximum higher scores of confidence, relevance and satisfaction = 20

$*_p$ <.05. (Choi & Johnson, 2005, p. 224)

Table 4-8 confirm that interactions about the video increased attention, confirming the retention pyramid's (Figure 4-10) assertions on the superiority of collaboration and discussions in enhancing the retention of concepts. The superiority of using the video in this manner over the textbook is apparent. The focus, however, should not be on the video itself, but on how it is used.

The research seems to suggest that learners will benefit a lot more if they use the gadget for peer learning and discussion, as also confirmed by the retention pyramid (Figure 4-10). The other finding was that seeing concrete examples reinforced understanding (Choi & Johnson, 2005). The same assertions were made by Mathomo (2006). Unless learners have the prerequisite knowledge, ICT programmes should not replace easily available concrete media. Once the concrete media has been used, ICT representations can be used to strengthen and 'remind' learners of the concept they were exposed to in concrete form. The use of video-based contexts shows that there was an increase in attention and retention, although the small sample size makes generalisations very difficult (Choi & Johnson, 2005). The video used in this research had problems opening due to the sizes of the video clips. This is just but one example of complications that can be associated with the use of technology. The selection of the tool used must consider the difficulties of using it such as opening, switching on, connectivity and similar considerations.

While videos are said to have a great impact on retention and attention, this assertion cannot be accepted at face value because this study establishes that videos alone without mental effort do not make a difference in the retention levels of learners.

The findings of the research showed that there were no significant differences in understanding, confirming that teachers have a variety of ways of teaching for understanding, but even greater focus should be placed on whether the learner would retain that understanding during delayed assessments and tests.

Table 4-9 Memo on ICT impact on retention and pedagogical practices

Concept	Effect on Retention	ICT Mediation/Pedagogy Issues That Come Up
Context allows transfer and application using real life situations	Allows for building of more connections	Affordance of ICT to create relatable contexts
Superior contexts—cheaper, available, faster, safer, portable		
Videos add interest component	Increases attention and encoding	ICT affordance for video
Combination of visual and auditory symbols	The combination enhances retention Multimodality benefits more children and enhances retention	ICT can combine a variety of symbols
Making of mental representations	Making stimulation reductionist	Multimodality affordance
Active engagement with ICT is important (Pearson)	Enhances retention	TV alone or listening alone might not be sufficient as an affordance
Fidelity of information	Learners can replay lessons and get the same accurate information	Affordance to record and replay
Events that cannot be easily represented	Creation of more relevant contexts at a fraction of the cost	ICT affordance for creation of virtual environments
Videos that increase the mental effort	Interactivity enhances retention and understanding	A good facilitator and interactivity affordance is important
Videos are more effective than textbooks Video plus text has a greater utility value	Multimodality	Video affordance—each lesson should have an accompanying video. Short is better to avoid habituation.

Table 4-9 above shows how certain practices impact on retention and the other categories.

4.5.7 Calculators: Martio (2009)

Martio's (2009) research focussed on evaluating the long-term effects of the calculators on the curriculum in Finland, and illustrated again that without a careful strategy in place, ICT use does not advance educational goals at all.

In 1981 and 2003, two similar tests were given to students that they had to do without using calculators. The results showed that curriculum changes negatively affected the performance of learners in mathematics. A brief discussion of the research will illustrate that the diminished performance in performance happened at the time learners showed an over dependence on the calculator for basic computation.

One of the questions asked in the 2003 test required learners to explain the meaning of (4/5).5. Only 6,5% of the learners answered the question correctly, confirming that learners do not possess multiple representations of concepts. Of the population, 47,8% had either incorrect computation and explanation or offered no answer at all. Quite worrying for a country that is supposed to be on an upward trajectory due to the inclusion of calculators in the curriculum. This immediately suggests that the use of ICT to simply get answers does not demand mental effort and defeats the purpose of viewing mathematical concepts from multiple formats and in elaborate ways, such as drawings, as a stories, as graphs or even dramatization. Where ICT tools take over basic computation skills from the learner, they become inhibitive rather than assistive to learning. Contrary to the general view that technologies always enhance mathematics performance, there was a general decline in mathematics performance from 1981 to 2003 in spite of the general uptake of ICT usage in mathematics education over the same period. Interestingly, technological uptake had the direct consequence of lowering performance in mathematics learning. This is not surprising because other researches have also shown that sometimes the removal of technology from the classroom can have a positive impact on mathematical performance (Cuban, Kirkpatrick & Peck, 2001), confirming that it is not the tool that strengthens mathematical teaching but how the tool is employed. Venkat and Spaull, (2015) agreed that technology cannot back up a poorly planned lesson. Curriculum changes between

1981 and 2003 included neglect of geometry, basic computations being done using calculators, mathematics becoming more descriptive, and definitions and proofs being largely ignored, possibly because the topics were not ideally suited to the tool. This once again confirms that ICT tools should not be the focus, but should complement and enhance the learning experience. The role of the teacher to identify which topics can or cannot be done with a specific ICT tool is still very important. An important lesson to draw from this is that lessons should not be made to suit technological devices, but the devices should be used where they successfully support a lesson.

The neglect of mental computation and basics seems to have affected the general performance of students in the subject. The same trend is evident in the topics on multiplication and algebra that have not been indicated in this research. Martio (2009) claimed that "… if calculators were allowed in the test, the results would have most likely shown different figures" (p. 53). Over dependence on technology destroys alternative strategies to solving problems and number sense. The aim of mathematics learning should not be the attainment of the correct answer, whichever way it is found. The processes that precede the correct answer really matter because it demonstrates conceptual understanding. The direct implication of this is that technological applications should allow for the verification of a step-by-step understanding.

Calculators and other ICT gadgets should be used in a way that promote mental effort or towards the achievement of a higher goal. As has already been illustrated, it is that mental effort that results in the internalisation of concepts (Choi & Johnson, 2005). Martio (2009) explained that while it was difficult to ascertain the contribution of the changes in curriculum and the changes in the teaching practices, the use of the calculators was one reason why the performance in mathematics went down during this period. This is important because not only does it dispel the assumption that the introduction of ICTs always results in positive results, but it also reveals that if the correct strategy for using technology is absent, the results will not improve. The results also show that students in Finland who have not learnt basic algebraic operations struggled at university.

The importance of this study is that it reveals the importance of ensuring that learners understand and retain the basic mathematical concepts and that they do not over depend on technological gadgets. The paper also revealed that calculators, like so many other ICT tools, were incorrectly used in Finnish mathematics classrooms. Martio (2009) argued that the use of calculators is overemphasised since professional users of mathematics do not use them and that since the introduction of calculators in 1975–1995, the poor results show and confirm the negative contribution of technological devices in mathematics education.

The failure of both the video-based contexts (Choi & Johnson, 2005) and the calculator can directly be attributed to a lack of mental effort that accompanies the use of the tool. The role of a good teacher in a technologically mediated classroom are facilitating activities that promote mental effort. This is important in that the social aspect of learning is very beneficial to retention. Technology use should lead to some more challenging task or activity that promotes mental effort. The research on the effectiveness of the video reached the same conclusion. Calculator use will, therefore, be more beneficial if it supports a more complex concept that requires higher levels of cognition.

Some would ask what is the role of mental mathematics? If it is just to get the correct answer, then the calculator is faster. However, the real aim of mental mathematics is exercising the brain to formulate patterns, become creative and solve problems quickly. Doing away with mental mathematics will affect learners' ability to think mathematically. The calculator can still be used to construct own questions, for verification, to check patterns and to enhance speed if there is a higher concept to be learnt.

Table 4-10 Reflection on findings from the paper on the impact of tool on retention (Based on Choi & Johnson, 2005)

Concept	Effect on Retention
Progression difficulties from middle school to high school confirm that there is a missing step	Pearson-test down to 2 years prior—identify the missing step
Introduction of ICT saw a decline in performance—an indirect relationship existed	ICT should not prevent mental processes of thinking
ICT use should not be towards getting answers but should lead to a higher goal. I have watched the TV in order to …. I have used my calculator to calculate in order to ….	The goal of using ICT should be higher than the activity of using ICT especially in relation to platforms that provide answers
Exercise the mind	Tulving-limiting—provide opportunities for elaboration
Do not outsource mental computation and knowledge of basics to ICT—Let the children learn to use their heads and not their hands (through clicking) to get answers	Mental work, calculations and patterns are still important even if learners have tools at their disposal to get a quick response
Diminishing returns of ICT utilisation	The function of the real teacher still exists. It seems greater movement towards E-learning during school years leads to a reduced computation levels

4.5.8 An iPad: Kilic (2013)

4.5.8.1 Introduction

The USA was selected as one of the most progressive and technologically advanced countries, and because the iPad was designed there and its best usage would be inferred from there.

Two articles were done on the iPad to reach an acceptable saturation level. The first one was by Kilic (2013) and the other was qualitative research done by Kaur et al. (2017). The research by Kilic (2013) focussed on the use of iPad and textbooks.

An iPad is a 9,7-inch touch screen computer made by the Apple Corporation. It was confirmed in the research that the integration of this tool in education has led to slight improvement in student achievement, participation and collaboration. Although it has already been established that it is usually how the tool is used and not the tool itself that positively impacts on mathematics learning, the size of the iPad suggests that it is very portable and can be used for anywhere and anytime learning, including homework.

The indicators of retention and the retention pyramid (Figure 4-10) confirm that learner participation, or active learning, increases levels of conceptual retention as it increases connections and allows learners to remember more, and as other learners in class verbalise their contributions, it provides multiple representations and cues through which learners remember the concept. Because iPads are flagged both as enablers and sources of distractions during learning, the role of the creative teacher in facilitating an ICT mediated classroom cannot be over emphasised (Liebenberg, 2019).

The tool is affordable and small, requiring less desk space, has thousands of applications, has less logistical issues, and needs less time to switch on. The tool already has an advantage over desktops because desktops generally take more time to switch on and their size do not make them ideal tools to use in class and at home. While the tool is relatively cheap in the USA, in South Africa, iPads are still considered an expensive luxury, with most costing around R5000, an amount most parents would find difficult to afford. The tool can now be used as a platform for other learning resources, for example, textbooks can be made in iPad format, with interactive colourful designs, videos, pictures, active learning, student motivation, individualised learning and collaboration. This tool needs to be placed alongside the classroom where the teacher always uses white chalk to write on a green or blackboard. The advantages are obvious, including the fact that with the traditional textbook and white board, the learning styles that are catered for are limited, unless the teacher is very creative. Again, research has confirmed that it is possible to design textbooks, such as the ones in Finland, to cater for a variety of learning styles. Besides iPads, smartboards, overhead projectors, interactive multimedia tools enhance learner achievement (Wand & Reeves, 2007, in Kilic, 2013). As has been already established, ICT tools cater for different learning styles, capture attention, allow for interaction with content and capture interest, all factors that positively impact on retention. The paper also claimed that in general, ICT build connections between concepts in more meaningful ways. The tool, when used effectively, provides images that accompany concepts, offer simulated environments and allow for representation of concepts in multiple formats, which strengthen connections around a concept. The greatest advantage besides the portability of the tool and the screen size is that at the click of a button, learners have access to numerous learning experiences and relevant connections.

iPads afford motivation that keep learners on task. The benefits of this are obvious and would include more opportunities for practice and rehearsal as well as for debriefing, all of which enhance retention. Kilic (2013) argued that "… elaboration, discussion and practice of new knowledge can bridge the gap between student motivation and achievement" (p. 5). In other words, there are practices that a motivated learner has to be exposed to if that motivation must result in achievement.

iPads afford more time for homework because the tool can be used in and out of school because of its portability. Although there are questions about whether the increase in time allocated for mathematics results in increased performance, the study of exercise books has indicated that most topics are hurried, with many getting just a single or no exposure at all. In such a scenario, teachers fail to provide opportunities for application and deeper understanding because of time constraints. Increasing time, both inside and outside the classroom simply lessens that pressure and allows teachers greater flexibility to plan lessons that capture attention and to teach for understanding and provide opportunities for over practice and elaboration. It has to be noted that Finland, one of the countries that is doing very well in mathematics, offers the least time for mathematics teaching. Their secret is simple: Their approach offers and builds connections at every opportunity, allowing learners to understand and retain concepts easily. Using my metaphor of retention, they learn and teach using 'blocks of blocks'.

Irrelevant iPad applications can be a distraction, something that would be equally true for devices such as cell phones, tablets and personal computers (PC) connected to the internet, which are likely to tempt learners to want to get into sites that do not enhance learning. In comparative terms, the laptop has fewer irrelevant applications and is easier to monitor because of the size of its screen and constraints on its functionality. However, Cuban et al. (2001) did not establish a correlation between the quality of learning outcomes with the amount of time pupils spend on using educational software applications.

4.5.8.2 Method

Learners with learning disability were issued with tablets rather than textbooks at a charter school in New Jersey. A mixed research method was used to gain an in-depth understanding of student behaviour.

The following were some of the observations from the literature section of the paper: Tablet computers "…yielded positive results regarding student engagement, homework completion and decreasing classroom distractions" (Manuguerra & Petocz, 2011, p. 61–65). Active learning promotes learner attention (p. 10) Attention according to literature leads to improved encoding which ultimately has a direct influence on retention as shown in the retention pyramid. iPads allow learners to go back and forth allowing learners to get more aha moments. Programmes that take learners back to concepts they would have struggled with, together with immediate feedback that support double looping, assist in the back and forth movement. This back and forth movement, especially working on a growing concept becomes one of the most important affordances of ICT tools. The paper also confirms that dynamic graphs aid in understanding.

In a technologically mediated classroom, the pedagogical role of the teacher shifts to become more facilitatory. Why is it important to remove the total responsibility of knowledge delivery from the teacher? Firstly, learners gain a deeper understanding if they are active participants in education. Secondly, as has already been noted by Venkat and Spaull (2015), some teachers lack content knowledge for the level they teach, especially in mathematics. Giving 100% of the time to a teacher who has a lower understanding of the subject they are teaching, would not be beneficial to the learners. ICT should be used even more for social justice, especially in schools that do not have good enough teachers. Finally, when the teacher cedes the bulk of the learning experience to the learners, this promotes greater collaboration that ranks high in terms of supporting conceptual retention.

4.5.8.3 Results

The result of the study indicates that iPad videos increase student's understanding and provided opportunities for elaboration. Elaboration according to the indicators of retention in the literature enhances retention. Again, the tools appeal to different learning styles which enhance understanding and encoding. Weinstein and Mayer (1986) used two lenses to describe learning activities from the cognitive perspective: rehearsal and elaboration. They defined rehearsal as referring to the repeating of the learning material so that it is not forgotten, accomplished by either rereading, or highlighting. The ICT has been found to be effective as a tool of rehearsal (Franklin & Peng, 2008)

Elaboration was defined to refer to "…the amount of details used to extend a response…" (Kilic, 2013, p. 22). In this research, it also refers to a variety of ways through which a concept can be viewed. Classroom setting that encourages elaboration includes taking notes to develop questions, making inferences between prior and new knowledge, demonstrating relationships, creating mental analogies. During elaboration, "…the student is fully involved in the processing of information by building the new knowledge on his/her prior knowledge and creating new cognitive frames, whereas in rehearsal the student is only occupied in keeping the information on a solid base" (p. 22).

There is no doubt that in some instances, especially for tactile learners, pen and paper notetaking would certainly be more useful in certain elements of elaboration such as note taking, role playing, mind mapping and maybe even creation of mental analogies, unless such content is interacted with. Such learners would most likely find opening a real book more appealing than scrolling a screen. However, computers are best at facilitating elaboration without need to use colourful markers. An app called "Notability" allows learners to do just that using a special magnetic pencil. What therefore comes to the fore is that even where technology lags behind, a non-technological approach of teaching, such a lack can easily be bridged and overcome through the development of apps that serves the required function. Pearson eBooks also have notetaking and summarising functions that are also interactive.

The iPad is easy to use because the operating system is closely similar to the one used by mobile phones. This would be the best advantage of using the phone because learners are already well acquainted with its functions and do not need to be trained in the use of the gadget. WhatsApp, Twitter and such other platforms have been used by other learners to elaborate on previous lessons through summaries of covered concepts. Specific rules need to be put in place in order for the platforms to achieve the desired goals.

Although the tool kept learners engaged, it brought with it a lot of distractions. 63% were playing games, 62% used laptops to check mail. In a scenario where just about 37% of the class is on task (Kilic, 2013), and the technology is expensive, many are bound to question the wisdom of introducing the tool into the classroom in the first place. It was observed during the lesson that children managed multiple applications during the lesson. Any good learning tool should allow the teacher to monitor and control what the learner can or cannot do with a learning gadget. On a positive note, it was also found that many children asked each other how to solve problems. Learners who worked collaboratively remembered concepts than those who worked alone (Kilic, 2013) again confirming the findings in the retention pyramid on the superiority of collaboration in enhancing retention. While tablets support collaboration, that in turn enhances retention of concepts, if not controlled well, learners who use technologies to do assessments, would find it easier to cheat by sending each other correct answers without the teacher noticing anything.

The implications of the distractions associated with the use of technologies are clear. It is very essential that learning ICT tools be reserved for only that because in the research, of the 317 applications that were evaluated, only 56 were suitable for a classroom setting. It is important for the teacher to select applications that are suitable for the learners. It becomes important to establish the criteria for a good tool that teachers would need to consider.

Figure 4-14 A summary from literature of what a good programme should do, according to this research(Adapted from Kilic, 2013)

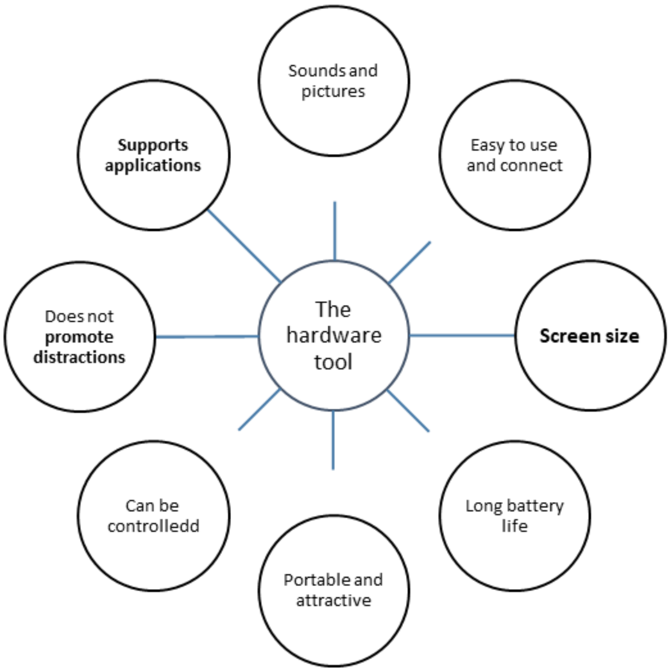

Figure 4-15 A summary on the qualities of a good ICT hardware tool (Adapted from Kilic, 2013)

The two summaries (Figure 4.14 and Figure 4.15) above are helpful in making a checklist of ideal hardware devices and programmes according to literature. A tool that lacks the bulk of the checklist items would probably be unsuitable in a classroom setting or would require the teacher's creative "revelation" to bring out its hidden affordances.

4.5.8.4 Discussion

The research was done on a small sample size of six students, something that might have an effect on the validity of the findings. Teacher asked learners to "DO now" a question on the smartboard "…activate prior knowledge" (p. 40). Questions were done on a smartboard with the teacher checking for understanding for 25 minutes. During the last 15 minutes' learners were given a week sheet that would be done either using ICT or a textbook, an opportunity for individual work although they were allowed to use a calculator. Extra time was used for revision to wonder around iPad applications.

For whole class activity, white interactive board is a better replacement of the traditional chalkboard because it is interactive, caters for far more learning styles, can offer simulated environments that can also be easily manipulated. The costs of good IWB are rather prohibitive with an average price of R25000 being way above what most schools can afford. A projector connected to a laptop can do a similar job at a slightly less amount.

Besides this whole class activity that supports collaboration, learners were provided with opportunities to work individually, again an important step that allows each learner to link new knowledge to their own baseline understanding of the concept. The lesson plan described can be diagrammatically represented as in Table 4.11.

Table 4-11 The implied lesson plan that was followed in the research(Adapted from Kilic, 2013)

Time	Lesson stage	Activity
0–25 minutes	Do new activity	Learners do an activity on the IWB and solve the problem in front of everybody. Teacher verifies for understanding. Focus is on a link to prior knowledge.
Missing step	Introduction	
Missing step	Demonstration and imitation	
26–20 minutes	Weekly classroom assessments	On some days done under text book or iPad conditions. Individually using calculators. Learners can revise work or surf applications if done.
Missing step	Conclusion	
Missing step	Home work to link with next step	

The research method allowed the use of both textbook and iPad. The results indicate that ICT used more for elaboration of old information than for rehearsal and elaboration of new information and that the tool was used equally for collaboration and for non-educational purposes. The results also indicate that there was an increase in student participation, prior knowledge had gone up which collectively enhances attention and motivation that positively impacts on retention. 90% of the learners preferred their textbooks to be loaded onto the iPad demonstrates the positive attitudes towards the tool that is essential towards an enhanced uptake of new gadgets such as ICT tools. Most students had an interest in Algebra 2 after using iPad with such interest promoting staying power and attention with 95% indicated that their engagement in classroom activities had increased.

The results show that 90% of the learners used their iPads for elaboration and the result for problem solving was 4,45/5 which confirm that learners were using the iPads to practice knowledge or a skill they had learnt in class. Viewed overall, the ICT did not make a greater impact in results.

Other quite contradictory findings of this research indicate that student achievement did not increase in comparison to traditional approaches. The other finding was that the iPad scored highest for participation, followed by collaboration, then logical thinking and problem solving and then finally lowest for rehearsal and elaboration of new knowledge. The results seem to indicate that ICT tools do not have a positive impact on retention, however nothing can be further from the truth. Done correctly, collaboration and participation score very high in the retention pyramid in enhancing retention. The small screen size prevents the tool from being used for presentation purposes, unless this is done in small groups. Presentations and learner opportunities to teach each other score very high in terms of retention in the retention pyramid. Once the teacher has found a way of dealing with distractions associated with iPads, the tool can be its affordances that support participation, motivation, collaboration, feedback and motivation.

In spite of the affordances offered by the tool, Kilic (2013) observed that "While these advantages are largely accepted by most iPad users, relying excessively upon an iPad for solving math problems may impair students' writing skills over time" (p. 64). The research on calculators highlighted a possible impairment of computational skills. Learners liked to write rather than typing especially the algebraic symbols. Research has already shown that writing is more than just a mechanical activity. The tool also tends to blur the clear and distinct boundaries between school work and play. (Kilic, 2013) can lead to distractions. Another source of distractions can come from notifications on the screen. A lot of people would say, if the tool is associated with so many distractions, why dare use it at all in the first place?

This research suggests that the technological tools should not be discarded. Rather they should be developed, like all other educational technological devices to prevent sources of distractions. Again, teachers would require training so that they are able to manage or minimise distractions. The other solution would be to use the tool for certain lessons where they make the most impact and lastly, careful selection of programmes and ICT tools that prevent distractions is important. Total reliance on the tool with all these questions around it at the moment would not be suitable. Other important observations of the paper include but are not limited to: learners sending messages to each other with answers. This can defeat the whole purpose of learning and would explain why the results of certain schools actually went up with the removal of the tool. Teachers also found it difficult to ensure learners who use iPads are on task. Use of tablets requires a lot of monitoring. This again confirms the difficulties of eliminating distractions on the iPad. In its brochure on eBooks, ITSI has come up with a package that is part of the learning programme that allows teachers to monitor whether students are on task or not.

On a positive note, the use of iPads requires less teacher assistance with the gadget and in cases where a teacher has to teach a class of 60 learners alone, the device can act as an assistant. Difficulties in monitoring whether learners are on task, will still need to be managed.

4.5.8.5 Conclusions

This article is insightful in that it shows that it confirms the possibility of using a variety of technologies within a lesson to achieve a different set of objectives. So for example, where the whole class has to be involved, an IWB works better than the iPad. The research also indicates that without a proper system in place to monitor whether learners are on task or not, the iPad and probably the tablet that is closely similar to it, can become more of a distraction rather than an aid to teaching.

4.5.9 iPad: Kaur et al. (2017)

The second research paper on iPads by Kaur et al. (2017) is a qualitative paper meant to identify the potential of iPads to supplement the teaching of mathematics to learners with disabilities. In this section, only aspects that have not yet been highlighted in the preceding papers were outlined. It is acknowledged that different mobile devices have revolutionised the way education is delivered and received. Different apps allow opportunities for creativity, collaboration, engagement, motivation, achievement and communication.

The advantages of mobile devices such as the iPads mentioned in the paper include versatility, portability, ease of access to information, and manipulation. These affordances support more opportunities for practice, easier and quicker access to information that requires low mental effort needed to solve problems that require a higher mental effort. The same affordances also support any time anywhere practice and the variation of the complexity of tasks and exercises, so that they start from simple to complex. In the books studied, it was observed that in practical terms, many teachers struggled with sequencing. Venkat and Spaull (2007) also highlighted the role of sequencing in supporting mathematical understanding.

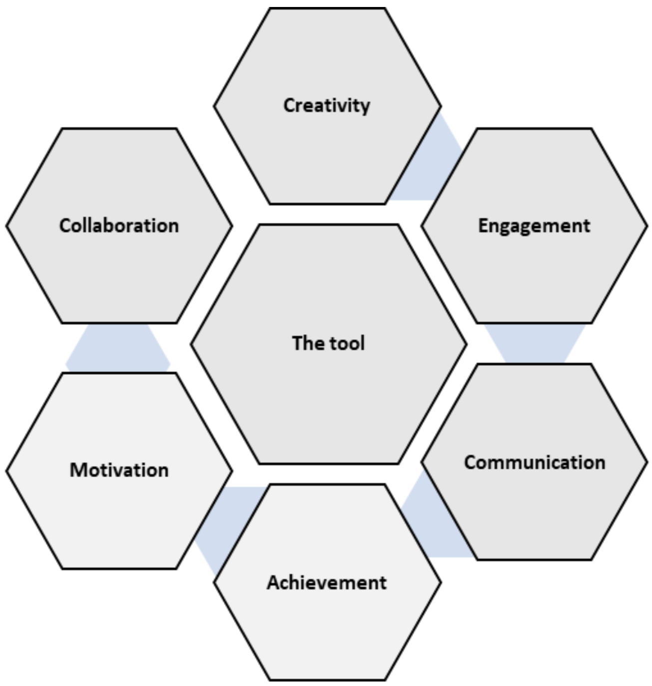

Figure 4-16 A summary of iPad affordances as listed in literature

A summary of the technological tool affordances is provided in Figure 4-16. Other iPad affordances include built-in features such as sounds, images, animations, text enlargement, highlighting, and others that allow content manipulation. Sound, images, animations all add to the interest component and aid in concept retention. This particular research focussed on promotion of conceptual understanding of numbers, order of operations, expressions, multiplication and division of struggling learners (Kaur et al., 2017). Although understanding is linked to and promotes retention, the two should not be confused.

The research was done over five weeks by 10 teacher candidates with 10 Grade 4 learners with learning disabilities. The teacher candidates had sufficient training in the use of technologies and had been exposed to some of the apps they were going to use. Teachers and learners who use ICT technologies should have received sufficient knowledge in the use of that technology.

4.5.9.1 Observations

The sensory and kinaesthetic experience with iPads increase motivation, control and independence, among others, which leads to learners being on task for longer periods of time, ultimately enhancing the retention of concepts. Independence allows the learner to work alone with minimal supervision. Arguably, one of the greatest affordances of ICT tools, besides catering for different learning styles and multimodality, is differentiation, which allows for differentiated instruction to meet the varied learning needs of students. This requires an awareness of different ZADs that aid in understanding, which eventually leads to retention. In the observed lesson plans in this research, it was clear that the teachers' lessons and activities were meant to cater for the average learner. The slow, the fast, the usually fast who do not understand and other different learners are not catered for. It was also found that the assessments and written work do not address the current understandings of learners, something that applications used in the Measure of Academic Progress (MAP) testing can easily do on iPad platforms.

The tool provides multi modal contexts that cater for different learning styles of different students (Kaur et al., 2017, p. 115), which impacts attention and conceptual understanding that enhance retention. Kaur et al. (2017) argued that iPads are superior to worksheets for both mathematics fluency and academic engagement. This is because the electronic worksheet is interactive and can be scaled up and down while allowing for interactivity and immediacy of feedback, creating for a double loop. The research also indicated that iPads increase motivation and behaviour for learners who are on task, leading to less problems with discipline and making maximum use of learning time. Some apps like Nearpod are specifically designed to enhance retention.

4.5.9.2 Method

Teacher candidates in the research created lesson plans every week, including the topic that needed to be covered, the standard the topic is aligned with, the app selected and the reason for selecting the particular app. The teacher candidates had to reflect each week on whether or not the app was effective. Free apps such as Chalkboard, Division for Kids, Division Wiz, Grade 4 Math, iTooch, Math Animations, Number Frames, Splash Math and Y Homework were mostly used.

It must be noted that in the lesson plans studied in this research, none of them had teacher reflection and none of them had any technological app listed to support the lesson; no rationale was provided when the chalkboard was used. Data was analysed and examined for commonalities with validity being enhanced by including quotations from participants, leading to the following six themes: How iPads are used as a guide, as an informal assessment tool, for different learning styles, to develop mathematical understanding, to improve engagement, independence and participation, and using iPads to individualise instruction. The use of iPads was evaluated under the following themes: Using iPads as a guide, for informal assessments, to meet different learning styles, for understanding, and for individualising instruction.

4.5.9.3 Results

The research showed that the use of iPad improved conceptual understanding and self-correcting feedback is a great feature, allowing learners to understand and retain concepts better (Kaur et al., 2017, p. 120). Discussion on immediate feedback as an affordance that supports a double loop has already been done. Learners were exposed to more opportunities for repetition, practice, were more focussed, less distracted and eliminated behavioural problems (Kaur et al., 2017, p. 120). Kaur et al. observed that most of the learners who were considered write offs in mathematics required extra time and differentiated learning to understand a concept. Things that provide this time, such as motivation, staying power, interest, less distractions, eliminating behavioural problems, in class all have a direct bearing on understanding and retention.

The only drawback of this research is that a period of five weeks and a small sample makes it rather difficult to generalise the results to a larger sample size. A longer study with in-service teachers would probably have arrived at a different conclusion.

4.5.10 Use of Tablets: Clarke and Svanaes (2014)

The research on the use of tablets was conducted by Clarke and Svanaes (2014). Although some comparisons can be made between tablets and iPad, it was necessary to make a study of tablets on their own to evaluate whether the size and functionality of the gadgets are very different.

Techknowledge for schools (Formerly Tablets for schools) is a charity group that supports schools and educators to transform education through the use of technology (Clarke & Svanaes, 2014). A lot of research has been done to evaluate the effectiveness of technology in education and the following is a management summary that emanated from the studies.

4.5.10.1 Management Summary

The use of technology by children is prevalent and many schools are acknowledging this by including technologies in education. At the same time, there are concerns that digital technologies might negatively impact education (Clarke & Svanaes, 2014), as seen with the

Finnish study on the impact of calculators (Martio, 2009). Similarly, there has been an unease about technology being a potential distraction leading to the banning mobile phones in many schools (Clarke & Svanaes, 2015). In spite of a lot of research and recently published papers that indicate that technologies could be beneficial, "… there is still some concern that there is little evidence of a direct impact on learning from technology" (Clarke & Svanaes, 2014, p. 3). As a result of this, global mobile technology use in education was suspended or abandoned in countries like South Africa because of issues of connectivity and breakages. Other issues that caused problems included, but where not limited to, connectivity, stay power of batteries, and costs of data (Clarke & Svanaes, 2014). Again, it is useful to study the nature of the mobile phones and how they were used to make a more authentic determination.

In research done by the University of Sheffield, 31% of the children under the age of five owned a tablet (Clarke & Svanaes, 2014), and hence, early digital literacy is possible in the UK and similar countries. The same opportunities are not available in most African countries where learners have to learn to use the device together with the content that is supported by the device. Technologies should be viewed as pedagogical tools that impact on certain learning styles such as learning through making, collaboration and inquiry (Clarke & Svanaes, 2014). Difficulties have been met where teacher tried to suit their pedagogy to the ICT tools they have access to.

Fullan and Donnelly, (2015) listed the following four criteria for new learning systems to have a positive impact, as illustrated in Figure 4-17: The tool should be engaging to teachers and learners, should be easily adaptable to use, needs to be ubiquitous access to technology 24/7, and finally, should be steeped in real life problem solving or utility. The four criteria support the indicators of retention through provision of connections, opportunities for practice, and motivating contexts that promote attention and allow learners to view the concept in elaborate ways.

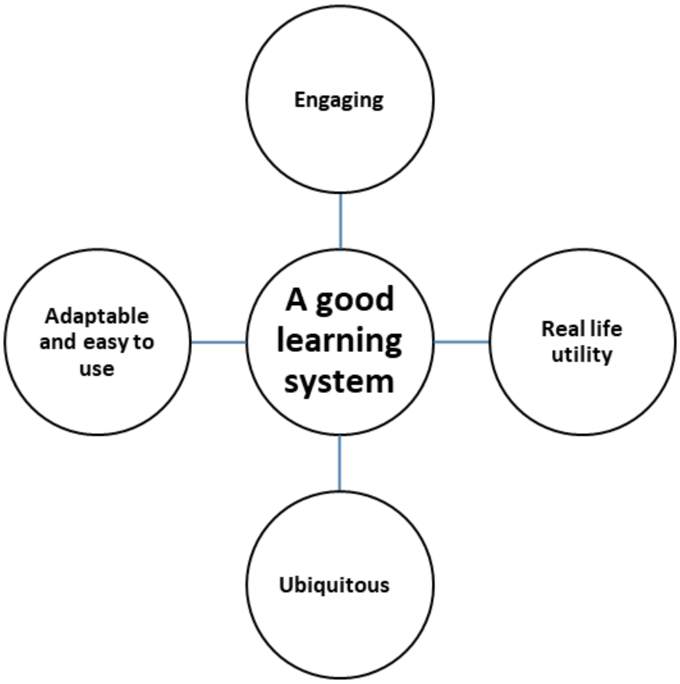

Figure 4-17 A summary of a good learning system that could act as a guide for the pedagogical setting (Adapted from Fullan & Donnelly, 2015)

This research highlighted some very important points on the use of technologies, including the fact that deep learning that is supported by ICT tools creates the learning, creating and doing. Just this statement caters for an active learner who becomes creative and applies their knowledge. The research goes further to say that learners should not only acquire knowledge but should connect these to real life problem that are supported by ICT (Clarke & Svanaes, 2014).

Sixteen out of twenty-three academic papers reviewed showed the positive impact of tablets on education (Clarke & Svanaes ,2014). As has already being mentioned in the study on the effect of video contexts on retention, "Using ICTs for lower level applications, such as computations, or demonstrations unaccompanied by exploration and reasoning severely undercuts their potential to expand and challenge student thinking and may in fact limit it" (Wiest, 2001, p. 44). This again points to the fact that technologies should not in any way replace activities that develop and challenge cognition. ICT helps with visualisations of mathematical ideas (Wiest, 2001). In relation to the indicators of retention, visualisations support different learning styles, add to connections, promote elaboration and enhance attention and the encoding process. Wiest (2001) categorised learning software under tool software that is used as an aid to another goal. The software "… facilitates the attainment of another goal" (p. 46). These could include spreadsheets, calculators and even videos that are used to support another activity that requires mental effort. The next category of software is the instructional software that "… is designed to teach students skills and concepts" (p. 47). A quick look of its overlapping categories, drill and practice, problem solving, simulations and games, assessment, remediation, and tutorial all confirm that they support indicators of retention. The third category of software is the internet, which can be used as a source of mathematical information. Actually, the National Council of Teachers of Mathematics, (NCTM, 1998) argued that "… every mathematics classroom should have computers with internet connections" (p. 50). Obviously this is going to take a lot of time in Africa where the internet is expensive and hugely inaccessible. The last category of software is programming, which is not directly linked to most of the indicators of retention, except for elaboration. These different types of software, for example, instructional software, are designed to teach students skills and concepts and include features that allow them to do drill and practice, problem solving and simulations, assessment, remediation and tutorials (Wiest, 2001). It is up to the creative teacher and schools to decide where they need to use ICTs to support retention.

Other observations in this research included the fact that if not used correctly, mobile technology can actually be a source of distraction (Clarke & Svanaes, 2014). In a report by Beland and Murphy (2015), removing mobile technology saw the exam results of the studied schools increase by around 6%, especially among low achieving and low income students. Cultural aspects that underpin learning could have had a role to play.

4.5.10.2 Results

According to this research, in spite of all the listed technological affordances, there is still a lack of evidence of the direct impact on learning from technology (Clarke & Svanaes, 2014). Again, conclusions can be drawn that in the absence of a framework, even a very good tool can be detrimental to the learning process. Schools should not invest in procuring technological resources that would not add value to learning. Prior and careful research is critical to the success of the process. The greatest benefits of ITC tools are their ability to cater for differentiated learning. Prescribed pacing targets the average learner and potentially cause a lot of damage to the very slow and fast learners who could have diminished retention potential as a result of lack of connections and habituation, respectively. With the advent of ICT tools, correctly used, differentiated learning has within it an inclusive component that allows for the tools to plan for the outliers. Table 4-12 summarises affordances of ICT tools as studied from literature in this sub-chapter.

Table 4-12 Showing affordances of the studied ICT tools as per literature

Affordances	Tools
Context-based learning that uses real life world contexts	iPad, tablet, PC, IWB
Portability	Tablet, iPad, calculator
24/7 accessibility	Tablet, iPad, calculator
Motivation	iPad, tablet, PC, IWB
Multiple learning styles	iPad, tablet, PC, IWB
Fidelity of messages	iPad, tablet, PC, IWB, video
Making of mental representations	iPad, tablet, PC, IWB, video
Feedback automaticity	iPad, tablet, PC, IWB, video, calculator (more to do with software)
Shifting control of learning to the learner	iPad, tablet, PC, IWB, video
Authentic situations	iPad, tablet, PC, IWB, video
Storage	iPad, tablet, PC, IWB, video
Report generation	iPad, tablet, PC, IWB
Interactivity	iPad, tablet, PC, IWB, calculator
Multiplicity of formats	iPad, tablet, PC, IWB, video
Differentiated and inclusive learning	iPad, tablet, PC, IWB, Mathletics, MyPedia
Gamification	iPad, tablet, PC, IWB
Speed	iPad, tablet, PC, IWB, video

4.6 **Enabling Pedagogy**

The research studied so far generated a lot of contestation around the use of technology in learning. Some authorities said technologies have no impact, some that it has a positive impact, and lastly, some that it has a negative impact on learning. Such questions can only be addressed based on whether a conducive pedagogical setting is in place or not. The fourth category on pedagogy addresses the fourth research objective and sub-questions:

Research Objective

To provide a pedagogical framework for using ICTs to support retention of mathematical concepts.

Research Sub-Question

What is the pedagogical framework that supports the use of ICTs to enhance the retention of mathematical concepts?

This sub-chapter is mainly focussed on the broad goal of identifying pragmatic pedagogical strategies that support retention in an ICT mediated classroom. To do this, lesson plans, mark sheets and other related documents were selected. The only research selected to address this broad goal was conducted by Cox et al. (2004) and commissioned by the British Educational and Technology Agency (Becta) on behalf of the Department of Education and Skills (DfES). The study investigated the impact of ICT on attainment based on published research and a few selected case studies.

The statement by Clarke and Svanaes (2014) that the impact of technology is "… dependent not only on the advances in technology but also advances in pedagogy and in our understanding of how to implement change" (Clarke & Svanaes, 2014, p. 6) underpins the rationale for this chapter.

4.6.1 ICT and Pedagogy: Cox et al. (2004)

According to Alexander (1992), pedagogy has two facets, namely teaching methods and pupil organisation. Although a paper by Linn and Hsi (2000) focussed on pedagogical issues for science, the following adapted pragmatic pedagogical principles would apply in an ICT mediated mathematics classroom:

- Encouraging pupils to investigate personally relevant problems and revisit their mathematical ideas frequently. Doing this would cater for the indicator of perceived utility, rehearsal, connectedness and elaboration
- Scaffold learner activities
- Provide multiple representations of concepts
- Engage pupils in sustained mathematical projects
- Establish an enquiry process that can be generalised and integrated with other subjects
- Scaffold groups to design criteria and standards
- Design social activities so that learners can learn from each other
- Scaffold pupils' feedback to explain their ideas

Cox et al. (2004) argued that effective use of ICT should focus on reasoning rather than on answers and enable learners to develop mathematical strategies and ideas connected to the real world (Cox et al., 2004, p. 15). The use of ICT should challenge learners' thinking. Connel (1998, p. 18) argued that "The presence of computers as a delivery system of static expert representations does not guarantee, and indeed may inhibit, the development of such pupil representations". Other research has also come to similar conclusions that where the technological tool provides a readily available affordance, another activity requiring higher mental effort should accompany it.

A study by Waxman and Huang (1996) indicated that the use of technology results in an imperative change in the teaching strategies from a traditional approach to one that shifts learning to the learner. ICT tool use would become beneficial only if its affordance to offer individualised learning opportunities are fully used. As has already been seen from literature, differentiation is afforded by portability of the tool, mapping exercises, flipped classrooms, baseline knowledge and a multiplicity of learning styles and formats that cater for different learners. Another study, by Dreyfus and Haveli (1991), concluded that if the teacher acts as a guide, even weak children are able to deal in depth with a difficult topic. If that is true, ICT tools would be very suitable to narrow the conceptual gaps of understanding among learners, gradually bringing them to a stable state of homogeneity that allows teachers to teach a class or group rather than individuals. The initial investments on ICT tools, especially in the lower classes, will pay off in higher grades when even the weaker pupil has been capacitated to deal with concepts together and not beneath their peers.

4.6.2 Documents

The themes raised in the documents used for data collection generally straddle across the four categories. Data was collected from documents that were regarded as pedagogical 'documents', which included lesson plans, mark summaries and learner books. A lot of data collected in this chapter is relevant to the other categories.

4.6.3 Lesson Plans

Four Grade 3 lesson plans, two Grade 5–7 lesson plans, four from South Africa, one Grade 7 lesson plan from Zimbabwe, one lesson plan from Kenya and one lesson plan from Finland (inferred from literature) were used. Two lesson plans from Kenya did not pass the credibility test and were excluded.

The rationale for analysing lesson plans was that they demonstrated the teachers' practical intentions, understanding of pedagogy, the subject and curriculum; and hence, some of the findings overlap with the categories of retention, the nature of mathematics and ICT tools. The structure of the lesson plans was carefully studied to establish whether the educators catered in their planning for activities that enhance retention and that show an awareness of the of the nature of mathematics, as well as whether an opportunity is available for ICT tools to enhance efficiency and overcome pedagogical hurdles.

4.6.4 South African Lesson Plans

Lesson plans from a selected school were analysed to evaluate how they address indicators or their sub-elements in the planning stage. Four sequential Grade 3 lesson plans and four sequential Grade 7 lesson plans were used from a school that I had access to.

Lesson plans from South Africa had the following basic features: Names of the teacher, the grade, the duration, the content and context, teacher and learner activities. I studied the first lesson plan and asked for the four previous lesson plans. The only difference between the five lesson plans were the topics and dates; the activities were similar for the successive lesson plans, even when the topics were different. None of the studied lesson plans were evaluated. All the teacher activities for the four lesson plans in Grade 7 followed the format in Table 4-13:

Table 4-13 A list of learner and teacher activities in the lesson plans

Teacher activities	Learner activities
1) Teacher demonstrates the concept 2) Teacher asks learners questions 3) Teacher gives individual written work 4) Teacher marks 5) Teacher gives homework	1) Learners follow example of the teacher 2) Learners demonstrate an understanding of the concept by working out on the board 3) Learners write provided work 4) Learners do homework

Although the learners in high school had calculators, the only media listed was the chalkboard, and there was no mention of how the chalkboard would be used in the lesson. Even at the planning stage, the teachers did not show any variations in terms of learning styles or topics that would require a different approach.

The generic teacher and learner activities in almost all the lesson plans studied in this research clearly demonstrated that nothing was done during the planning point to individualise learning by the teachers. Considering the diversity of topics, learners and context, it was worrying that all the lessons were approached uniformly. When one considers that some of the learners are not catered for, this easy way of planning becomes the basis of exclusion in our schools, because it fails to demonstrate an awareness of the individuality of learners.

It was evident that generally, with one exception, planning was not done properly, because there was no links or connections between lessons or subjects. In the referred textbooks, I noted that practice questions were similar for all learners with only one or two challenge questions in Grades 3, 6 and 8.

The following observations were made regarding the observed lesson plans evaluated: There is no provision for prior knowledge, or if the teachers were aware of it, it was not stated in the lesson plan, although it is implied in the curriculum and textbooks. Only in one Grade 7 lesson was baseline assessment mentioned. Again, there are hardly any connections in the topics taught. For example, in a series of lesson plans analysed, the teachers did not show how the current topic was linked to any previous concepts or topics. The indicators of retention clearly show that these connections are essential for the enhancement of retention.

Learner activities were generic: The lesson plans evaluated were silent on the technologies used, verification for understanding or prior knowledge, application of knowledge, and besides homework, it is not clear how or where learners will do activities that promote retention, even in the lesson plans from schools that use ICT tools for teaching mathematics. As was mentioned, teacher activities for different subjects and lessons also seemed generic.

While the textbook activities (Platinum Grade 8 Mathematics) seemed to indicate the need to cater for a variety of learning styles, the activities in all but one lesson plan catered for a single learning style (mainly reading); and if indeed the lesson plans were executed as planned, it meant that only a few learners were able to understand and retain concepts.

With the exception of two lesson plans, planning was generally done for a week or even sometimes for two weeks. The lesson plans were not broken down into segments that indicate time allocated to different lesson stages and what would be done at each stage, so it was not possible to verify the amount of time reserved for practice or collaboration. The indicators of retention show that practice and over practice is essential for retention.

In the lesson plans, there was no mention of practice items for learners to do. In a few instances where these are mentioned, it is a page from the textbook or a work sheet that has similar exercises for everyone. There is no evidence of differentiation and all learners were asked to do exactly the same activity and amount of work. A differentiated approach is necessary to smoothly move learners from one ZPD to another without skipping any conceptual gaps that militate against making connections, which is essential for retention. It became clear that in the learning process, learners are not being treated as individuals but as members of a homogeneous group. The teacher learner ratio is probably why teachers found it difficult to individualise learning for each of the approximately 30 learners in a class. In the South African lesson plans there was basically no mention of how media would be used in the lesson.

4.6.5 Zimbabwean Lesson Plan

I could only study one Grade 7 lesson plan from Zimbabwe that had a slightly different structure and detail. The structure of the lesson plan was as follows: Prior knowledge was mentioned in the lesson plans as generalised assumed knowledge for the whole class, and these assumed skills, attitudes and competences were listed. The major drawback of the list was that it was not directed at the prior skills of individual learners, possibly because of the unavailability of these reports or the difficulty of generating reports for each learner. The lesson plan had a section on assumed knowledge, an introduction, demonstration by the teacher and imitation by learners, group activities and report back, and then finally, the conclusion. In the introduction, it was briefly mentioned how the lesson would be introduced. Considering that recency and primacy are suggestive of the beginning and end of lesson as the best learning time, I think that not much effort was made to make the introduction memorable.

One lesson plan mentioned that the teacher was going to do a demonstration. The lesson plans indicated that after the stage of imitation, the learners would be asked to take part. The teacher wrote the problems on the board to help the whole class understand the concept. In one of the researches, this process was done using the IWB, whose affordances include interactivity, catering to different learning styles, connections to different simulated and authentic contexts, motivation, and gamification. If one considered the amount of time the teacher has to write on the board instead of facilitating lessons, it would be easier to see the benefits of having IWBs that can provide those questions at a click of a button.

Group work was provided to learners, although no mention was made of how the groups were distributed. A report back was the next activity, where the learners would teach others how they solved their problems. Teaching others and collaboration activities rank very high on the retention table. According to the research, there was no differentiation in terms of complexity between the work given to two different groups. Next was individual written work, but once again there was no mention of differentiation in the work learners were supposed to do. A follow-up in the learner books showed that usually learners were not provided with homework, or when it was provided, only four to five items, which are insufficient to retain a concept, were given.

Media was listed in both lessons plans to include the chalkboard and the textbook, but with the exception of the textbook where the homework was to be extracted, there was hardly any mention of how media was used.

Although the conclusion of the lesson is supposed to be memorable, in this lesson plan, the teacher decided to use it to give homework. That in my opinion is a lost opportunity. An interesting activity that assists with understanding the concept would have been ideal.

4.6.5.1 Enablers and Barriers to Retention

I conclude that the Zimbabwean lesson plans showed that tools were used insufficiently and the supplied list of tools did not explain how they would be used. In terms of the stimulus, there were connections to previous work in the observed lesson plans, but it was generalised. There was no differentiation in the extension and remedial work, and generally learners had to do the same homework and classwork. Again, both lesson plans had the teacher-centred approach that seem to work well for teachers who are overloaded and cannot provide individualised lessons. Addressing the issues of learning styles that promote attention and understanding and individualisation of practice and feedback still make ICT tools relevant in the Zimbabwean context.

4.6.5.2 Exercise Books

Selected mathematics exercise books from Grade 2–8 were studied and analysed to evaluate how they address the nature of mathematics and the indicators of retention, as well as to uncover the teacher's pedagogy in the teaching of mathematics.

Only one of the five books had evidence of linking topics to the previous work by way of a revision or baseline activity at the end of the week. Generally, there was no evidence of the teacher ascertaining or using baseline knowledge. It is worth noting that this step of giving a revision exercise was not mentioned in the planning stage. It is also worth noting that in all the books evaluated, by October the last four revision exercises had not been marked and were not mentioned in the lesson plans. The failure to mark books denied learners feedback and an opportunity to correct misconceptions. The efficient basis of retention is conceptual understanding, without it, retention becomes rote learning. A failure to mark books denies the teacher the opportunity to verify learner understanding on the concept.

Only one of the five exercise books had examples written in the book to verify for understanding. Marking consisted mainly of a long single tick, which also denied learners a chance to confirm their understanding of the concept. Verification for conceptual understanding underpins practices that promote retention.

In the grades evaluated, representation was mainly in symbol form. There were very few diagrams or number sentences and very little step-by-step working (my observation indicated that the classes used calculators). Looking back at the problems that learners were doing, it was evident that any learner who knew how to operate the calculator could do very well in the test without demonstrating any mental effort. This question was included at Grade 8 level:

$\sqrt{64} + \sqrt[3]{8}$, and such similar questions.

It is possible for learners to get the answers right without demonstrating an understanding of the concept. Using ICT in this manner does not promote greater mental effort by the learner.

A single representation format of concepts again denies learners who learn differently an opportunity to benefit from the lesson.

In the literature section, it was established that retention cannot be separated from understanding (Maffei & Marriotti, 2007). A learner cannot be expected to store concepts they have not yet acquired. In the analysis of documents, books particularly, an analysis was undertaken to verify whether the initial teaching itself confirmed that learners have understood the concept. In all the Grade 3, 7 and 8 exercise books studied, homework was given but work had not been marked (there was no verification for understanding). In the South African context, I also witnessed learners being given homework that was totally different and disconnected from the work done in class. In all the evaluated books there were little evidence that learners were asked to apply knowledge learnt in class in a different context.

Table 4-14 An analysis of Grade 2, 3 and 9 exercise books

Theme	Grade 2	Grade 3	Grade 9
Is there evidence of connections to previous lessons or subjects and is learning contextualised?	Yes for both	In the exercise books there is no evidence of any connections	There is a progression but no connections between topics
Is there evidence that concepts have been applied?	The last five exercises in both books were practice items	No evidence of application	The last five items were practice items with no application
Is there evidence that the concept is being presented in a variety of forms?	Concepts represented symbolically in both books	Concepts are represented symbolically	In both books concept was represented symbolically
Is there evidence that the lesson was interesting as measured by achievement?	Books for extremely good learner and struggling learner were taken. In the last five books both books were not marked	There is moderate achievement	The excelling learner is achieving but last two exercises are not marked. The struggling learner has one long ticks in most of pages and last two have not been controlled. In an unmarked revision exercise, there is evidence that learners are copying answers from the back of the textbook
Are children getting opportunities for adequate practice during class and homework? On average, how many practice items are learners exposed to per single mathematics lesson?	Average number of classwork items ranged from 6–10	Average number of items are 10	Average number of class items ranged between 8 and 10 items
Is there feedback that suggests the educator is using existing knowledge as a basis for new knowledge?	The teachers were both following the tracker	There is hardly any feedback in the learner books	One teacher was behind his plan and the other was on par with the lesson plan

4.6.5.3 Marking

In the studied Grade 8 learner books, the teacher used a red pen to make ticks, signed and wrote a date. In all the studied books, I noted so many errors and misconceptions that escaped the attention of the teacher, with learners mostly marking for themselves and the teacher sometimes shadow marking wrong items. Marking in the learner books also did not happen immediately, as seen in exercises that were not marked for more than two months. Where the teacher did not see any sense, they drew a line right across the work. In one Grade 9 book, the teacher wrote "What is this?". I believe that this type of feedback only demoralises learners, leading to them dislike the subject and not doing well in it. Most of the informal work was from revision activities in textbooks that are found at the end of the term. The five books evaluated in Grade 3 and 9 had more than seven exercises that were still to be marked. By October, both Grade 8 mathematics exercise books had last been marked in August. It was difficult, therefore, to imagine how the teacher proceeded to a new topic without verification for understanding. New lessons were therefore not connected to learners' prior understandings of the concept. It was also evident that learners were being deprived of an opportunity to benefit from feedback through reengaging with items.

4.6.6 South African Assessments

Informal assessment records were selected from learner books and mark records. Once a month, Grade 8 learners were given monthly tests in mathematics, translating to close to eight such tests per year. Five of the eight informal tests had not been marked by November 2018, and therefore, although they appeared in the learner books, they were not recorded. If feedback has any function in retention, especially through the double loop, it can be assumed that learners only benefitted from five tests during the whole year. A comparison was made between the informal test items and the final paper for 2018 mathematics, where it was seen that approximately 70% of the concepts in the Grade 8 practice paper were present in the end-of-year matric paper, implying that formative assessments are not being fully used to support summative assessments.

The research looked at end of Term 1, 2019 mathematics assessments at Grades 3 and 9 levels. I selected these grades because they are exit grades for their respective phases. The following emerged from the assessments: All learners were given the same question paper. My attention was also caught when I compared two scripts of the same learner for Term 1 and Term 2. The learner had failed a concept in Term 1 and had also failed it in Term 2. In between the two assessments, I did not see any intervention that sought to correct the misconception. This, to me, was indicative of the fact that there was no intervention done, although the mark sheet indicated that there was a problem. Either the mark sheet was not used to establish understanding, or as a result of pacing, the teachers lacked the time to assist individual learners to overcome conceptual barriers. Considering the potential for ICT tools to individualise learning, it was quite clear to me that a programme directed at such interventions would have been of great assistance. Again, immediate feedback and learner records need to be readily accessible and specific if they are to be used to assist with intervention. Eight of the questions given were simple recall questions. It has been mentioned in the literature that application actually enhances retention, and asking learners at a single comprehension level denies them an opportunity to enhance their retention levels. Fifteen of the twenty questions were at a symbolic level; none of the papers asked learners to illustrate their understanding through drawing a variety of concepts. Errors showed procedural deficiencies, for example 4×7=26. Such errors can easily be corrected through practice and pattern making. A calculator would probably be a very good tool for learners to check their answers until they overlearn and remember their tables and bonds.

At Grade 7, where calculators are allowed, one of the questions I analysed required a learner to solve 4500/90; instead of dividing, it is assumed that the learner actually added, but possibly because they were using a calculator, they did not verify that the number actually made sense. Their answer of 4 590, which is far greater than the correct answer for this question, had the learner chosen to check, showed a lack of number sense and the dangers of overreliance on a technology to learners who lack number sense. Observations have been made that software tools should be used to aid processes only if there is a higher aim to be achieved.

Table 4-15 Showing Mathematics summary marks for Grade 2, 3 and 9 for end of term, 2019, at a school in KZN

	Levels and percentages							Total
	1 0-29	2 30-39	3 40-49	4 50-59	5 60-69	6 70-79	7 80-100	
Grade 2	0	0	3	11	4	4	8	30
Grade 3	0	0	0	2	7	8	10	27
Grade 9	3	8	14	8	9	6	3	51

The research looked at the way the assessments for different grades was done to come up with the marks in Table 4-14. In the foundation phase, formal assessments were done as soon as the learners completed a topic or a section of a topic. With the upper classes, however, although the term assessment plan (TAP) indicated that they would be done at the conclusion of a topic, assessments were delayed to the end of term, close to two months after the first lesson of the term was taught. At Grade 2, 90% of the learners had 50% or above in mathematics during Term 1. At Grade 3, that figure improved to 93%, but drops down to 51% in Grade 9. While it may appear as if learners in higher grades are struggling, this is far from the truth. It is the timing and not the performance on assessments that has changed, with the former being assessed immediately after lessons and the latter being given delayed tests.

The results for Grades 9 seem to paint a true picture for delayed tests that confirm that the teaching strategies in South Africa are not supporting the retention of concepts. By the time senior students do assessments, they would have forgotten what they were taught in class. This observation seems to confirm that the problems of mathematics in South Africa are problems of retention more than anything else. Research has confirmed that how the learners are taught and what learners do between assessments contributes to how well they do in delayed assessments with ICT. Absence of multiple formats of representation, multiple exposures to concepts, and generic lesson plans that only cater for one learning style are indicative of the deficiencies of the strategies being used to teach mathematics.

Out of the seven topics that were done in Term 2, only two topics were formally assessed. The rest were left out, although they had been given as informal revision tasks. When I checked these in the learner books, I discovered that the informal tasks for the other topics that were not formally assessed were not marked. One of the indicators of retention is perceived utility, which implies that if learners do not see the value of what they learn, there is no motivation to retain it. A failure to assess all topics and mark work sends an indirect message to learners that certain topics are unimportant and not worthy of attention. Had learners been told that all topics are to be assessed, one would assume that they would receive greater focus. Right from the onset, it is a good idea to explain to learners how the concepts learnt will be assessed and applied, so that they pay greater attention to it and retain it better. The Mathletics programme I analysed had multiple activities presented in multiple formats and levels of complexity for each of the topics in the CAPS curriculum, signifying how ICT tools can be used to support perceived utility of each topic in the curriculum.

In the studied assessment, there was no evidence of any connections or a smooth flow between topics. It seems topics in between had been left out, creating apparent gaps in the knowledge bank of learners. I contend in this research that ‘gaps’ militate against both understanding and retention of concepts.

Grade 8 had three assessments during the 10 weeks of Term 1 of 2018. The three assessments were all done in the last three weeks of March, towards the end of the term. Such a distribution results in massed testing that tends to work against retention. The assessments for Term 2 were written assessments for both the assignment and project. The problems related to content and pedagogical knowledge raised by Venkat and Spaull (2007) could be the real reason why teachers are not varying assessments as stipulated by the TAPS.

There was no analysis or diagnostic document that tried establish the learners' weaknesses and how to address these. I did not see any item analysis for any of the assessments done.

4.6.7 Conclusion

There is very little evidence of connections between the topics or to any other subject. Learners were given the same tests and assessments irrespective of their differences. I concluded that tests and assessments were not promoting further learning because they were not differentiated, analysed and there is no intervention in place after their administration. With the exception of the calculator, there is no evidence that any tool was used during assessments or tests. Even the calculator at Grade 8 level was used for easy questions that could have been done without the tool.

Table 4-16 Comments on a studied mark sheets

Concept	Effect on Retention	ICT, Pedagogical or Retention Issues That Came Up
Number of learners Grade 8 class had 55 learners doing mathematics	Average of one assessment per three weeks Difficulties of marking and feedback Difficulties with individualisation Difficulties with catering for multiple learning styles Difficulties of making individual connections	ICT can personalise learning easily ICT can automatically mark work and offer feedback ICT affordance—storage of records ICT affordance—making lessons interesting ICT—preloaded practice and assessment activities Easier marking means assessments can be given when needed Tests and assessments can be given at the click of a mouse
Sequence of topics There is no progression between assessed topics. Progress or retrogression is quantified on things that are not similar. Topic-to-topic assessment allows teachers to gauge progress. Topics could be similar or show connections to prior topics	Assessed topics are not even related	ICT programmes such as Mathletics have a variety of assessments on the same or related topics that can be scaled up or scaled down At a click of a mouse, topics can be sequenced
Feedback and evaluation of assessment There is no feedback or item analysis	Specific feedback allows the teacher to make timely interventions so that learning gaps are closed before a new topic is tackled	ICT can offer specific comments on areas that leaners struggle with
Frequency of assessments Three assessments were given per term towards the end of the term. It was inferred that these were given because the teacher wanted marks but there was little time left to use assessments to drive learning. Assessments were bunched up together and not distributed.	Only three prescribed tests/assessments given during the whole course of the term, affecting practice and automaticity. Research has shown that over learning reduces forgetfulness	ICT allows the teacher to give related assessments and test whenever these are needed
Number of tested items	With the exception of control tests at the end of the term, a maximum number of 15 items s were given in one assessment	ICT allows learners to do twice or thrice as many items as the traditional approach The marking burden is taken away from the teacher and so learners are able to do even more practice
Item analysis—what type of questions do learners get right/wrong? There was no item analysis		
What is the diagnosis?	Focus seems to be on the mark with no evidence that it was used for later intervention	Some software programs(Mathletics) identify a problem, explain what needs to be done, and while the concept is still fresh, offer the learner another chance to retry the concept

The reviewed lesson plans from both South Africa and Zimbabwe had one thing in common. They had separate teacher activities and learner activities. In a class where there should be integration and connections between teacher and learner activities, this distinction suggests a disconnected approach to teaching. In terms of an enabling pedagogy, best practices from different countries have been identified and will also be implied through activities that promote productive learning. Best practices include the following:

- Not every lesson requires technological tools to be successful.
- There are numerous ways of teaching a concept (Triantafyllou, 2016)
- Motivating environments are important (Mart, 2011) and support attention to the concept and promote longer on task time.
- It is the responsibility of the mathematics teachers to inspire a positive vision of the subject (Goos, 2006).
- Teachers' understanding of the subject is important (Zhao & Frank, 2003). Besides the available technological tools, it is the teacher who verifies understanding, selects assessments, sequences topics, identifies learning styles and so on.

Mathematics teachers in Finland are autonomous and reflective experts (Niemi, Auli & Arto, 2015). In the reviewed lesson plans, reflective practices are absent. Teachers need to evaluate the successes or failures of their lessons and the materials and tools used to mediate the lesson. A failure to evaluate lessons confirms that the teacher, and possibly, the child is not connecting prior concepts to new learning. This way of teaching and learning does not support the retention of concepts. The shifting of control of learning from the teacher to the learner (November, 2010) suggests that there should be a lot more learner activities than teacher activities, and these should include collaboration activities, discussion and other activities that allow learners to demonstrate their conceptual understanding.

Connections should be visible between concepts taught and the subjects taught. For primary school level, it would be ideal for each grade to have a class teacher who teaches most, if not all, subjects. Allowing teachers to teacher classes for longer periods gives them an opportunity to make hierarchical and vertical connections. The issue of grade and subject teachers, especially in the primary school needs to be relooked. An equally good tool should allow learners to build conceptual connections or provide simulated environments that act as cues to support retrieval of concepts when needed.

Teaching from the known to the unknown is important, and yet, this progression was not clearly seen in the studied lesson plans. It is easier to arrange ICT work in this manner with teachers blocking certain topics until learners mastered the basic concepts. Teachers should select concrete media first, especially where these are readily available. Again, a good teacher should start each lesson with a short baseline assessment that informs how the lesson should unfold. Daily written work at the end of the lesson should be marked before learners start a new concept so that the teacher can link the learners' prior understandings to the new lesson.

Teachers should provide application opportunities for concepts learnt to enhance their utility value. Opportunities should be provided to identify and solve practical problems in their communities using concepts learnt in school. Major challenges to opportunities for application that need to be overcome include prescriptive pacing, lack of creativity, lack of planning time, assessments that do emphasise application.

Strong introductions and conclusions that cater for as many learning styles as possible allow as many as possible learners benefit. Every lesson should include these two basic steps. Research has already confirmed that primacy and recency enhance retention. In the studied lesson plans, there is hardly any mention of an introduction or a conclusion, and how these are used to make learning more memorable. Actually in all but one studied lesson plan, the conclusion was "giving learners homework".

Pedagogy should provide educational opportunities in an egalitarian manner and use resources efficiently (Sahlberg, 2012). In Finland, every student in upper secondary school has a personalised plan (Sahlberg, 2012). This requires us to rethink education, so that the plan ceases to be about what the teacher intends to do in a day but rather what the learners needs to do in a day, taking into consideration their prior knowledge and the skills set required to move to the next step. Where "… the unified curriculum sets certain expectations for all students, regardless of their abilities or prior learning" (Sahlberg, 2012, p. 24) it tends to disadvantage learners who lack foundational knowledge. The author further stated that learners must have differentiated learning for different students (Sahlberg, 2012).

Especially in the primary school, teacher must carry out assessments so that they are not hurried in their teaching. Teachers should also ensure that all topics taught in class are given equal utility value. Prescribing pacing and content defeats the purpose of differentiated learning and does not take into cognisance variations in learner backgrounds. In a setting where the teacher uses ICT tools that allows them to individualise learning, their role should become more of a facilitator with less teacher talk (Sahlberg & Berry, 2003), allowing the learners to do the bulk of the work. Of even greater importance is teachers' knowledge to determine when to use which tool to support learning. In the research by Gambari et al. (2017) to compare the effectiveness of traditional approaches to teaching with e-learning and blended learning, the results indicated the superiority of blended learning over e-learning. "The superiority of blended learning over e-learning and traditional method stem from the fact that blended learning combined the potentials of e-learning and traditional teaching methods together" (Gambari et al., 2017, p. 33).

Mathematics pedagogy must be premised on the basis that all students have a right to access mathematical culture, can all become powerful mathematical learners, must be responsive to realities found in the classroom, must assist the learner to develop into a holistic individual, and must promote conceptual understanding, procedural fluency, strategic competence and adaptive reasoning, (Antony & Walshaw, 2009). The authors said, "Students need opportunities to practice what they are learning whether it be to improve their computational fluency, problem solving skills, or conceptual understanding" (Antony & Walshaw, 2009, p. 14),

For learners to make sense of a new skills, they need to connect it to existing mathematical understanding and gain opportunities to apply it in everyday contexts (Antony & Walshaw, 2009). It has been claimed that technologies can link students with the real world and that good teachers should use a variety of representations in their teaching (Antony & Walshaw, 2009).

"Teachers with in depth knowledge have clear ideas about how to build procedural proficiency and how to extend and challenge learner ideas" (Antony & Walshaw, 2009, p. 25). The authors further said that teachers also need an understanding of individual students. In the current context, this knowledge is an awareness of where the child is going, where they are and where they are coming from, the connections needed between these steps, and most importantly, the learning styles through which learners best learn and understand concepts. The implication is that mathematics teachers should at the very least be able to effectively teach a grade below, a grade above, as well as the current grade in order to make and prepare for anticipated conceptual connections.

CHAPTER 5: SYNTHESIS OF RESULTS

5.1 **Introduction**

The data collection and analysis stage strongly indicated that ICT tools are not a panacea to every learning problem in South Africa. Technology should, therefore, only be selected after a holistic evaluation of a variety of factors that affect the pedagogical setting. It follows that the way ICT tools are used in certain countries should be regarded only as a guideline and not a prescription on technological use. The selection and utilisation of ICT tools should be informed by the needs and requirements of particular children.

To address the main research question "To what extent are ICT tools enhancing retention of mathematical concepts", it is ideal to make a list of the hidden and perceivable affordances of ICT tools that were studied in the research and match them with the indicators of retention that promotes connectedness, sequence and hierarchy in mathematics; eliminate the current hurdles; and incorporate these affordances into mathematical learning. The first hurdle is that South Africa has at least two 'types' of mathematics, the official mathematics and the practical mathematics. While the mathematics reflected in the curriculum and textbooks appears to be sequential, connected and hierarchical, the mathematics being taught in the classroom, as evidenced by the studied documents, is definitely not. The first and probably greatest task before addressing the role of media in education, is to align the mathematics being taught in class with the mathematics being advocated for at policy level.

5.2 **Align Mathematics**

The first step towards an alignment of the official curriculum with what teachers do in the classroom is to offer realistic expectations regarding what teachers can and cannot do in the provided time frames, taking into consideration the heterogeneity nature of learners in a class. It is not surprising that learners in South Africa are underperforming in mathematics, because although the official curriculum of South Africa shows hierarchy and some sequence, what is presented in class is very different.

The first step towards that would be the removal of prescriptions that put so much pressure on the teachers and has had a huge negative effect on sequencing, connections and opportunities for retention. Prescription is a major threat to individualised learning. The second, would be the addition of ICTs to manage many tasks such as feedback, motivation, practice, sequencing, assessments, record keeping and intervention in order to free a lot of time, and in the process, allow learners to build stronger mathematics connections and sequence concepts in a memorable way that supports further learning. In both instances, time is the determining factor. Any practices that free learning time, including integration, flipped classrooms, class teaching and teaching grades for a longer time, require attention. Together with this, there is a need for schools and teachers to plug time leakages at the beginning and end of year when very little learning takes place.

5.3 **Train the Teacher**

It is essential that teachers know the correct tool to use in a particular situation, when to increase and reduce mental effort, and when to focus on and emphasise indicators of retention. Besides training, creative teachers are required to use the ICTs' hidden affordances to their advantage and to know each learner's baseline knowledge. This requires dedicated teachers who plan for each learner, each day (as opposed to weekly or fortnightly) in order to cater for individualised learning, upon which retention is based.

5.4 **Select the Correct Learning Tool**

In terms of perceivable affordances, the calculator and the video seems to feature the least. With more creative use, the tools are capable of even more affordances. The creative teacher is a must in ICT mediated teaching.

The tablet tends to feature so much as having many distractions, and so without a creative and capable teacher, the inclusion of these tools can do more harm than good. Where they really must be used, I suggest reduced exposures so that learners do not over depend on the tools.

Together with the hardware device, teachers should be able to select a tool that allows each learner to connect to their prior knowledge and follow their learning path. Such a tool must be able to keep and avail records for intervention as needed.

Research indicated that where technological tools have failed; it was usually as a result of distractions associated with it and a lack of higher mental effort that accompanied its use.

5.5 **Selection of the Relevant Administrative Tool**

In order for teachers to succeed in teaching memorable lessons, they require tools that help them to assess, mark and offer feedback, that keeps records for intervention, and that allows them to control the sequencing and hierarchy of those assessments.

Having ascertained which tool offers which affordance, it is now possible to match these affordances to the elements that support retention, bearing in mind that the five indicators of retention all support connected, hierarchical and sequential mathematics as illustrated in Figure 5-1.

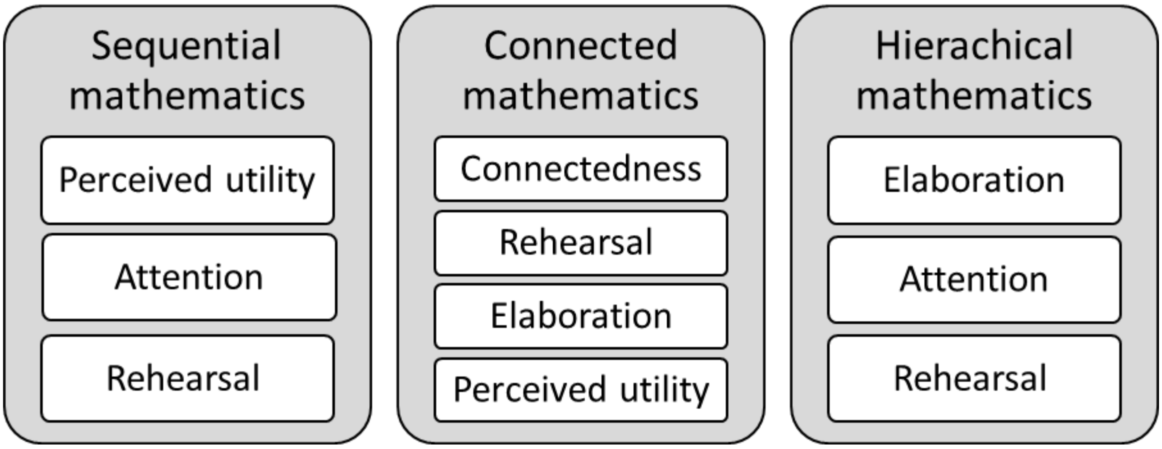

Figure 5-1 Literature on indicators confirmed that although they can be categorised under sequencing, connecting and hierarchy based on the specific nature of the mathematics they address, they overlap many times.

Figure 5-1 also subtly suggests that it is possible to have connections without a strong emphasis on hierarchy, to have hierarchy without strong conceptual connections, and to sequence activities without necessarily arranging them in a hierarchical order. Indicators that support connected, sequential and hierarchical mathematics and their sub-categories are represented in Table 5-1 and matched with the relevant technological affordance.

Table 5-1 Matching the indicators of retention to the ICT affordances

Indicator and the Nature of Mathematics Supported		ICT Affordance	Example of Tool from Literature
Perceived utility	Sequence	Authentic situations that allow learners to apply knowledge learnt in class, feedback utility during double looping	Simulated environments afforded by the tablet, the iPad, videos, Mathletics, and MyPedia
	Hierarchy		
	Connections		
Connectedness	Hierarchy	The storage facility allows teachers to connect new experiences to past achievements. Multiple formats of concepts can also be easily visualised, 24/7 availability	Mathletics, tablet, iPad, IWB
	Sequence		Mathletics, tablet, iPad
	Connections		Videos, iPad, tablet, IWB
Elaboration	Hierarchy	Multiple formats, multiple learning styles	Mathletics, tablet, iPad, IWB
	Sequence		Mathletics, tablet, iPad
	Connections		Videos, iPad, tablet, IWB
Attention	Hierarchy	Gamification, interactivity, multiple formats, motivation, provocations, multiple learning styles	iPad, tablets
	Sequence		
	Connections		Videos
Rehearsal	Hierarchy	Immediate feedback provides the double loop, lots of practice exercises, gamification promotes on task activities, individualisation of learning that can be scaled up and down, offering of multiple exposures on a concept	Mathletics, tablets, PCs, calculators
	Sequence		Mathletics, tablets, PCs, calculators
	Connections		Mathletics, tablets, PCs, calculators

The indicators above and other factors related to pedagogy, ICT tools and retention can further be broken down into higher categories (Table 5-2) that are indicative of sequential, connected and hierarchical mathematics. The interactions between factors that originate from the three different categories become even clearer at this stage, and it becomes easier, if not expedient, to fit in the nature of mathematics with the emergent categories of ICT and retention. Connected, sequential and hierarchical mathematics is afforded by ICT tools, pedagogical practices and practices that support retention.

Table 5-2 Showing the matrix of elements used for coding the nature of mathematics. The interconnections among the categories are getting clearer with retention featuring the most.

		Nature of Mathematics		
Criteria Affecting Retention	**Source of Emergent Category**	**Sequential**	**Hierarchical**	**Connected**
Multiple formats	Retention		√	√
Catering for multiple learning styles—multimodality	Retention		√	√
Gamification	ICT			√
Back and forth movements	Retention			√
Verbalising ideas	Retention			√
Simplex to complex, known to unknown	Retention	√	√	√
Number of exposure to concept	Retention		√	
Application of concepts	ICT		√	√
Collaboration opportunities	Retention		√	√
Marking and feedback	ICT/Retention	√	√	
Individualised learning plan	ICT	√	√	√
Differentiated assessment	ICT	√	√	√
Class teaching	Retention			√
Baseline assessments	Retention	√	√	√
Teacher learner ratio	Retention	√		
Corrections and interventions	ICT/Retention	√	√	√
Intervention reports	Retention	√	√	
Lesson evaluations	Retention	√	√	√
Learner achievement before next lesson	Retention	√	√	√

It is clear from Table 5-2 that the sources of elements that support the nature of mathematics are mainly being derived from the category of retention. At the end of each document analysis, a brief discussion on enablers and barriers to retention was undertaken.

5.6 **Addressing the Question "How ICT Affordances Enhance Retention of Connected, Sequential and Hierarchical Mathematics"**

In the discussion that follows, ICT affordances and how they enhance indicators of retention that ultimately impacts mathematics that should be taught in South Africa will be evaluated. To answer the research question "How ICT enhance retention of mathematical concepts", mathematics, retention as well as affordances will be broken down and elements that support either connections, sequence or hierarchy in mathematics will be described. The ICT affordances will also be broken down and incorporated in the activities that support sub-elements of retention and the nature of mathematics.

It has been established that although in practical terms mathematics is not being taught sequentially, with evidence of clear hierarchy and connections, official documents are to a large extent advocating for that. Incidentally, literature reviewed so far on the retention of concepts confirm the importance of sequencing, connections and conceptual hierarchy in order to support further understanding. That understanding, together with connections, directly impacts retention positively. Put differently, it can be said that the mathematics being taught in South Africa should be taught in a way that supports the goal of understanding and retention (although the study of pedagogical documents seems to paint a gloomy picture).

The discussion below seeks to address how ICTs enhance retention of mathematical concepts. The mathematical concepts are further broken down into the three natures of official mathematics established in this research which are connectedness, hierarchical and sequential.

5.7 **Enhancing Connectedness in Mathematics**

5.7.1 Multiple Formats

From the data collected, especially from the lesson plans and learner books, it is clear that learners are not being exposed to multiple formats of concepts, which ultimately negatively impacts on their retention levels. While this affordance is not the preserve of ICT tools, it is acknowledged that YouTube videos and other visual representations can be used to represent concepts in elaborate ways. This too caters for multiple learning styles, which ICT tools are known to afford.

5.7.2 Connections Across Subjects

Connections across subjects and across grades are indicative of mature pedagogical practices. It is ideal for teachers to connect topics and concepts to other topics and concepts taught in other subjects. Again, research implies the importance of teachers teaching a grade for more than a year to provide the necessary connections between grade concepts. The reasons can be categorised under familiarity, baseline knowledge, record keeping and connection making; all affordance of ICT tools. The ICT tools and programmes can act as a familiar teacher who keeps baseline records of the learner, adapts new content to baseline knowledge, maps current understandings and connects prior understandings to new knowledge.

I think teachers should take their classes for the duration of a phase. Grade 1 teachers should teach their children up to Grade 3, Grade 4 teachers up to Grade 6, Grade 7 teachers up to Grade 9, and Grade 10 teachers up to Grade 12. Many different teachers during the course of learners' life at school disrupts connections. A single teacher in a phase strengthens foundational concepts, and aids in perceived utility of learning when the teacher uses the previous years' concepts to drive current learning. Although it would be difficult practically, the ideal situation is that learners should have a single, excellent mathematics teacher to optimally benefit in their learning. ICTs, though not considered a human teacher, can step in to cater for many of the benefits of having a single teacher. To put the issue of occasionally changing teachers into perspective, an analogy can be used of a patient who changes doctors every year (who does not share their patient history as is happening in many educational settings) and the possible challenges they would face to highlight the problems of changing teachers each year. From my own experience as a teacher, very few teachers share (or study) the history of learners before teaching them. Whether the teachers use ICT tools or not, at least a day should be set aside for teachers to share the history of each of the learners they teach. This, of course, highlights the disadvantages of consistently changing schools, with learners who have been taught by fewer teachers, who know them intimately likely doing comparatively better than their peers with a different experience. The ICT tools, especially applications that afford assessments such as Mathletics and MyPedia, can be used quickly to assess prior understandings so that the teacher builds on these to plan later, individualised lessons.

5.7.3 Physical and Mental Connections

Mathematics learning should never be done in a vacuum. Teachers must create mental and varied physical contexts to prevent habituation that cause boredom and allow learners to have a rich set of descriptors that act as cues during retrieval. Such simulated environments are easily created using ICT tools.

5.7.4 Connections to Real Life Problems and Challenges

Learners can use the internet to get more information about different societal challenges that can be used as a learning context for mathematical concepts.

5.7.5 Strengthening of Mental Neural Connections

Concepts are better retained if they are practised adequately, and as research has shown, single exposures are hardly enough, even for superficial learning. The number of activities most applications have on a topic and the storage function that allows learners to do activities over and over again are beneficial for retention. At Grade 9 level, for a topic on numeric and geometric patterns, Mathletics, for example, has no fewer than 200 practice items per topic, compared to a maximum of 46 in the Platinum textbooks. This in no way discredits the quality of the textbook. It only shows the limitations of the printed text in terms of space and size of the book that attempts to be formatted like an e-book or a mathematics programme.

5.7.6 Flipped Learning, Time Savings and Increased Connections

Research has indicated that a single exposure is not sufficient for the promotion of retention. In a discussion with teachers on the importance of completing all topics and teaching the topics thoroughly, the major issue that came up was time. On one hand, the DoE is tracking coverage of the prescribed curriculum, and on the other, they want teachers to teach for understanding. The two do not coexist. And then there is the issue of marking that teachers have to do, with more marking being required if more activities are provided to support rehearsal. ICT tools allow learners to use home time or any other free time to further engage with the concept and get immediate feedback on their performance. This way, through applications that afford gamification of concepts and enhancing on task time, learners get to practice more concepts than they would without tools.

A brief look at the number of items given as homework to Grade 6 learners indicated that at most learners were given 4–5 items. The gamification affordance is very important since it increases interest in the subject and allows learners to initiate learning for longer periods of time. A report from the DoE indicated that a lot of time is lost, especially after the end of tests at the end of term. According to my own observations in learner books, most learners stop going to school a month before end of term because according to them, “tests are done”. Putting this together with say, a month long vacation in December, means that learners would not have engaged with mathematical concepts for approximately two months. ICT tools such as tablets and iPads that are portable are very suitable for flipped activities.

5.7.7 Connections Through Teaching Others

Activities that allow learners to present to others, teach others and collaborate rank very high on the retention table. While videos are multimodal and appeal to a variety of learning styles, without mental effort such as collaboration activities and opportunities to engage further with the concept, they are not beneficial. Power point presentations can now be prepared and presented from a cell phone, laptop or PC, allowing learners to engage at a higher level with the concepts that support retention of concepts. In a presentation by Elevate Education (Elevate Education, 2019), a group that supports learners with study skills, the use of phone recorders and similar functions that support learning through learners sharing their learning experiences and collaborating with others was encouraged. Similarly, platforms such as TWITTER and WhatsApp can be used to share and summarise mathematical ideas.

5.7.8 Connections to Age Levels or Conceptual Understanding Levels

Visuals that are age appropriate encourage learners to interact with activities and increase contextual descriptors of concepts and the multiplicity of mental images. Pictures enhance the learning experience, especially at foundational levels, because they cater for different learning styles. This not only increases love for the subject, but leads to enhanced understanding and consequently retention, which supports even further retention.

5.7.9 Connections Through Games

Research has shown that learners remember activities that bring them joy. It is a fact that children love games, and any activity based on games and that brings them happiness will not be easily forgotten. Willis (2007) calls it the neuroscience of joyful education. She goes on to say that “…when we scrub joy and comfort from the classroom, we distance our students from effective information processing and long-term memory storage” (Willis, 2007, p. 1).

5.7.10 Recall and Transfer

The quick accessibility of concepts via ICT tools allows the teacher make learning a future oriented process and to demonstrate how the present is connected to the present and the past. Ensuring that learners possess a deep understanding of prior concepts through elaboration, practice and application in diverse settings is essential for learning.

5.7.11 Growing Concepts

The back and forth movement of a growing concept indicate that even as it is growing, the concept is still linked to the initial experiences where it was introduced. ICTs have the capacity to store many lessons and at the click of a mouse access a variety of lessons and learning experiences that strengthen and 'grow' the concept. During their own time, or even in class, learners can access lessons and learning experiences they struggled with that could have bearing on the current topic. It is easy for teachers to immediately ask learners to stop what they are doing so that they engage with a topic at a level of development that supports current learning. ICTs allow for incremental assessments because of their effective record keeping function. Hierarchical and sequential mathematics imply a carefully structured and growing subject.

5.7.12 Introductions and Conclusions

It was observed during data collection that at least at the planning stage, lessons lacked introductions and conclusions. A lost opportunity indeed, because research has indicated that recency and primacy are critical for the retention of concepts. A powerful tool such as a IWB and YouTube videos, among others, are readily available to make introductions and conclusions more memorable. In my observations, most of the lessons started with a different mathematics problem, and yet, this could be the opportunity to establish baseline knowledge, make connections with the previous lessons or show the utility of the topic to be learnt through a very powerful learning medium such as a YouTube video, which will form the basis of activities that require mental effort.

5.8 **Hierarchical Mathematics**

5.8.1 Individualised Learning

Truly hierarchical mathematics is not just composed of topics that build upon each other. Rather, for each child it depends on understanding that builds upon a previous understanding, achievement that builds upon achievement, firm concepts that build upon firm concepts, and ZAD that build upon a ZPD, as illustrated in Figure 5-2. Granted, it is implied in the hierarchical nature of mathematics that activities that learners learn must be sequenced, not only for the grade level, but for the different learners in that grade who might have varying ZAD on the concepts under study. That is not easy, especially for a teacher of 30 learners. One of the affordances of ICT tools is that of individualising learning. This implies that a single teacher must be aware of each learner's hierarchy and devise a learning plan unique to each learner. Individualised learning allows learners to learn at their own pace and to connect concepts learnt with prior knowledge, which enhances further retention.

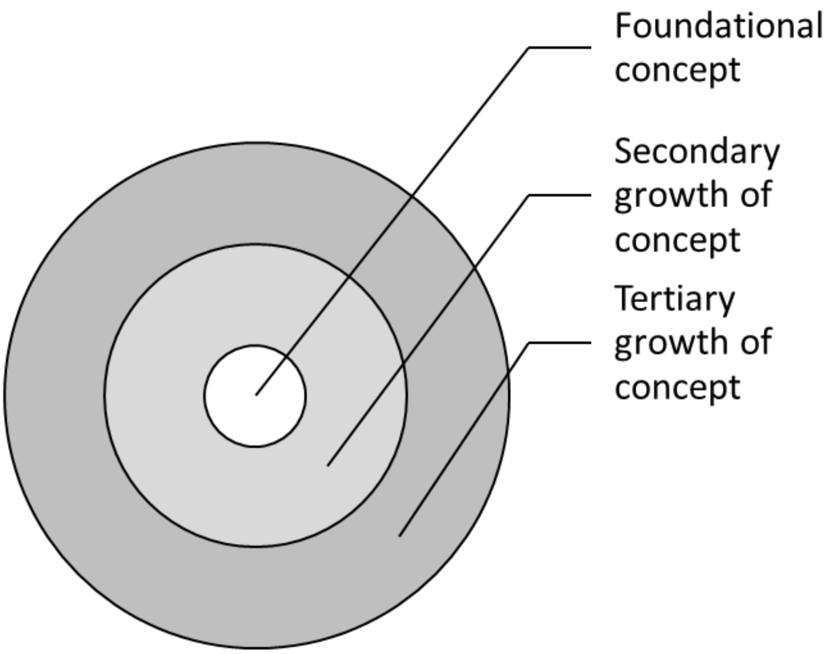

Figure 5-2 The hierarchical growth of a concept. Growth is effective and devoid of gaps if there are connections between concepts and if they are sequenced correctly.

5.8.2 Baseline Assessments

Baselines assessments can be used to quickly establish learners' understanding on a certain topic, starting with concepts a step lower than the one to be learnt. Learners can now be grouped according to their ability levels in temporary groups based on their understanding of concepts to collaboratively work on new learning experiences. An ICT application can be used to divide these groups further and more efficiently to vary and individualise the complexity of concepts and scale them up and down, depending on learner responses. According to their brochures, MyPedia and Mathletics programmes can map the growth of learners in a concept, which provides both the teacher and the learner with useful information required for intervention.

5.8.3 Seen in Multiple Formats

Conceptual hierarchy should be based on a firm understanding of concepts. In their totality, indicators of retention describe an ideal mathematical layer that forms part of a hierarchy. Such a layer is only solid and complete if it has been rehearsed, used, elaborated on and connected and engaged with in a variety and interesting ways.

Basing on the above observations, the learning journey at school should be composed of layers, and not grades. A learning layer that supports hierarchical, sequential and connected mathematics should take more or less than a year, depending on the conceptual level of the child, and should only be complete when it is successfully retained (which is the focus of this research), understood and applied. The composition of each layer in the grade should be present in each lesson. Every concept learnt must have numerous connections and be used, motivated and elaborated upon and be sufficiently practised. Research has indicated that overreliance on technologies, especially to get answers, has a negative impact on computation. However, learners can use technologies to practice their tables and bonds, build number sense, and use calculators for verification. Caution should be used so that before learners use technologies for verification and speed, concrete objects had been used to enhance understanding and the concept had been taught from simple to complex, according to Bandura's reference of enactive to symbolic forms of representations (Bandura, 1997).

5.8.4 More Capable Others to Close Conceptual Gaps

Venkat and Spaull (2007) found that lack of pedagogical and content knowledge is a problem. YouTube videos and other interactive teaching applications can be used to strengthen conceptual understanding and ensure that learners build concepts upon solid concepts.

The other surest way for both learners and teachers to be certain of their understanding is the feedback that comes from marking and other such activities. Technological devices that offer immediate, detailed feedback allow teachers to offer accurate interventions based on the generated reports on learner performance. Technological tools that offer printed reports that are shared with other stakeholders are beneficial.

5.8.5 Evaluation

In the studied lesson plans and assessment records, I noted that none of these had been evaluated. This could be the result of an inability to do so or a lack of time. Accurate evaluations should be based on data generated, which is one of the affordances of ICT tools such as Mathletics, according to the information in their brochures. Readers are Leaders, an offline application used for English, has a report generating tool that immediately gives an accurate report on the success or weaknesses of a learner on a specific skill; such an application can be developed in mathematics. Evaluations, therefore, must identify what individual learners are struggling with and should be done prior to the start of a new lesson.

5.8.6 Constant Retrieval

Research has shown that the ability to quickly access relevant information promotes further learning. Constant retrieval can be used together with opportunities for rehearsal to enhance conceptual retention. This requires that learners overlearn, practice, build connections and elaborate on the concept and be exposed as often as possible to spaced assessments and tests. As has been explained, ICT tools are best placed to support these indicators. While practice of skills and drill is usually held in contempt in mathematics, it is so much better than relying on calculators for answers, and therefore, still have a role to play in the subject. Motivation that keeps learners on task and feedback induced double loops are very important for the retention of prior knowledge. Spacing out has already been tagged as an enhancer of retention.

5.8.7 Simple to Complex

In one of the studied Grade 6 mathematics books, I saw that although the textbooks offered some hierarchy in the way concepts are approached, in the actual teaching the teacher did not follow that sequence. He started with more difficult parts of the concept and worked backwards, resulting in learners failing to grasp the concept, as indicated by low marks in the exercises. ICT applications must be carefully sequenced so that they present concepts from simple to complex, from known to unknown. In the studied teacher documents, I saw that what the textbook promotes is not practised in class. The major advantage of ICTs is that of interaction with content in a deeper and relational way, something that textbooks are incapable of affording. It is easier, therefore, to align teaching to the connections, sequences, formats and frequency of activities using ICT tools than it is using a textbook. It is better for schools to start small, and research even proposes that the curriculum be rearranged so that it starts with foundational skills, such as tables and bonds and number sense, before delving into complex concepts.

5.8.8 Competency Rather than Age-Based Grade Promotion

One of the most important factors to be discussed is whether grades based on the years completed in school rather than on competence should be a factor when categorising learners in school. My proposition is that, especially in mathematics, learners should be given grade levels that are consistent with their understanding of a concept. The current scenario of teaching is mainly focussed on teaching for averages and not for understanding and retention by individual learners. If a learner, for example, is in Grade 3 but their conceptual understanding is at Grade 1 level, teaching Grade 3 concepts will create gaps that will make it even more difficult to address. It would be more beneficial for that child to be taught concepts connected with their current understanding. A normal teacher would find this very difficult; hence, ICT applications responsive to the successes and weaknesses of learners as they work through activities must be developed. MAP testing does this very well when establishing competence levels for different learners.

5.8.9 Testing All Topics

I noted in the observed assessments and exercise books that the last topics of the term and year were hardly taught and assessed. Over a number of years, this creates problems, especially when concepts based on the skipped concepts must be taught. ICT tools can be used to teach and store tests and assessments for all topics. The limited time could be redeemed through making connections and using flipped classrooms. Again, the idleness created by learning breaks seems to have a disconnecting function on learning and creates a ‘buffer’ between different terms’ concepts. More frequent but shorter holidays could be essential for learners to engage with connections in a consistently spaced way that enhances retention.

5.8.10 Huge Store of Graded Assessments and Records

The superior storage capabilities of ICTs allow them to store a huge amount of graded activities that can easily be used when a child moves from one school to another. That way, even if the child is new to a school, they can be placed correctly in a context that builds upon their prior understanding. The ideal situation is for every learner in South Africa to know with some degree of certainty, the level of understanding they have in mathematics. ICT mediated activities should readily offer such information on a concept-by-concept, topic-by-topic and level-by-level basis. For example, John is at a Grade 3 level in multiplication and at a Grade 6 level in the topic on perimeter; knowing this would allow the teacher to offer relevant and accurate interventions and ensure he moves at his pace and not at the pace of his peers. ICTs can also allow learners to select the concept at a level they can engage with and make it possible for each mathematics learner to experience success, which in turn increases motivation.

In Finland, for example, there is a lot of intervention, especially in the foundational stages because once learners are left behind, it is very difficult for them to catch up. And once learners catch up, it is difficult for them to be left behind. An individualised learning plan can be followed to address the identified weaknesses of learners and allow those who are faster to follow their own learning plan. At the moment it seems that most of the time topics that are understood by most of the class are repeated, while those that really must be focussed on are ignored. A huge store of assessments is also very important in South Africa where teacher absenteeism especially in black schools has reached alarming levels (Reddy et al, 2010). Learners can have another teacher in the absence of their actual teacher who can teach and assess them as well as offer feedback.

5.9 **Sequential Mathematics**

Sequencing topics and concepts relates to how they are ordered in order to make the best connections, and this would sometimes require that teachers learn from the experts, such as in the Finnish scenario. While it is possible for the goals to be catered for simultaneously in the lesson, the average teacher should ideally teach for understanding, retention and then application of the concept. For easier implementation, these three steps can be broken into steps that together will still result in a retained concept. The sequencing of topics that allow them to run concurrently with topics in other subjects or topical issues and following a graduated degree of complexity allows learners to make firm connections that support retention.

5.9.1 Sequencing Based on the Degree of Complexity

As has already been mentioned, the sequencing of concepts and activities on the basis of complexity is important to teachers as it allows them to determine with a certain degree of certainty the area/s that learners are struggling with in a concept. A good ICT application should provide a series of intervention exercises with micro steps that address identified weaknesses. ICT tools can be used to sequence not only topics, but a series of activities within that topic. Sequencing of activities and topics could be done following learners' individual plans, and Mathletics has a feature that allows the teacher to block the progress of learners until they master foundational skills. Learners' mathematics plans are not fixed plans but rather at-the-moment plans based on current understandings, which could change for the better or worse at any moment. These changes require observant and alert teachers.

5.9.2 Knowing When to Assess or Test

Programmes such as Mathletics allow teachers to time activities and assessments to enhance optimal levels of understanding and retention. Research has highlighted the advantages of spaced out tests and assessments. Teachers must understand when to administer which assessment to space them out and derive the maximum benefits from assessments and tests. This will be a futile endeavour if feedback is not provided timeously. ICT tools make it easier for teachers to provide immediate feedback. In my own observations as a principal, teachers hold back and delay assessments when they have not yet marked the previous ones.

5.9.3 Sequencing Assessments to Promote Learning

Sequencing assessments, other than possibly end-of-year examinations, should not be focussed on marks. It is the focus on marks that results in learners not studying soon after writing tests. It is the focus on marks that results in learners being absent for close to three weeks at the end of every term, losing cumulatively about four months of learning time in a year. It is that focus on marks that results in the DoE requesting marks from schools before the end of the term, causing the whole system to either slow down or even shut down. In an ideal scenario assessments are used as a teaching and diagnostic tool that helps identify gaps in learning and areas where learners are struggling. This requires record keeping and immediate feedback that forms the basis upon which lessons are planned. This is not happening at the moment. Lessons and activities in learner books are not connected in any way. Most of the assessments are not even marked anyway. ICTs can play a very big role in addressing these concerns.

5.9.4 Mental Activities from Known to Unknown Baseline Assessments

The Finnish experience puts paid to the generally accepted view that ICT tools are panacea to all mathematical challenges in South Africa. The role of the teacher in sequencing activities from ICT initiated provocations to the use of concrete media and other visuals is still as relevant today as ever.

Other pedagogical issues to take note of include that if learners are to be assisted with retention, the context used in teaching should be available during assessments and tests to act as cues. This is confirmed by Tulving & Thompson's (1973) encoding specificity theory. If learners are taught concepts using ICT, it would be wise to assess those sections using the same contexts learners were exposed to during learning; because what good is a context and a cue if it cannot be used during retrieval? For example, where a project was used to apply a concept, assess using a project.

Teachers should also let learners know that all the topics and concepts learnt will be assessed. Careful lesson planning is important and should cater for the different learning needs of the class, as well as use opportunities that support optimal levels of retention. It could include the following:

- Individualised lesson plan for different levels of comprehension
- Topic
- Previous conceptual level
- Current conceptual level
- Next conceptual level

Table 5-3 The ideal mathematics lesson plan according to literature

Lesson Step	Activity	Nature of Maths and Indicators Addressed
	Listing assumed prior knowledge. Ideally divide class into groups that share their entry level knowledge Authorities Baseline assessments using ICT could be done before a new lesson or after the last lesson.	A list of learning styles to be catered for needs to be provided
A strong introduction to capture attention—primacy Step 1	Lesson introduced by the teacher or learner or via a video etc. To cater for the indicator of utility, explain to children why they have to learn the concept and where they can apply it	Powerful introduction for primacy—IWB or any media that appeals to different learning styles
Step 2	Verification of and connection with prior knowledge. A quick assessment is important. The teacher should not proceed if most learners are struggling	IWB/Ordinary chalkboard. This can be done on the board and on ICT tools.
Step 3	Demonstration by the teacher or learner At least one example for at least three categories of learners on a concept that address the day's lesson should be provided.	IWB/Ordinary chalkboard. Ordinary concrete objects can also be used
Step 4	Verify for understanding. A quick assessment that is marked by ICT tool is beneficial	IWB/Ordinary chalkboard
Step 5	Collaboration, peer teaching or demonstration and debriefing aid retention and understanding. A task that can be done by a group is beneficial. The whole lesson does not have to be based on the ICT tool. Learners should be provided with opportunities to make presentations of their understanding of the concept. PowerPoint is a strong and powerful tool to use in this regard because it supports multiple learning styles	Mobile technology/group task initiated by technological stimulation
Step 6	Individual work to offer more practice, elaborate ways of looking at the topic. The tool allows learners to do more practices that is marked immediately. Where this is impossible, teachers should device ways of making sure that students get immediate feedback. This will form the basis for the next lesson.	Mobile technology/worksheet
	An opportunity to apply to real life problems	A practical lesson or if there is no time, an ICT simulated problem
Step 7	Conclusion either by the teacher or learner Never forget to powerfully tie up the lesson—children remember the last powerful thing that was said	IWB—Powerful conclusion-recency
Step 8	Homework—the flipped classroom with contextualised problems	If tablet was used in class, use worksheet for homework and vice versa in order to cater for learners with different learning styles

Provision of prior, current and projected conceptual levels as indicated in Table 5.3 are very important as it allows teachers to quickly go back to the previous step if a homogeneous group of learners encounter conceptual difficulties, and build from there. Teachers can also easily and quickly direct learners to their next activities if they are competent in the skills being taught. The back and forth movement requires keeping individual records and a present and permanent store of activities, which can only be sufficiently afforded by ICT tools.

Lesson planning should be based on individual children and not the teacher and should be responsive to changes in the understandings of children. The level of understanding would dictate if the intervention should be ICT based or based on the concrete understanding of the teacher. As has already been established, in Finland every student in upper secondary school has a personalised plan (Sahlberg, 2012). I argue that such a plan is even more ideal for lower grades that form the foundation of later academic success. This allows each learner to move from a firm position of conceptual understanding to the next. ICTs can be easily scaled up and down for each category of learner, so that while learning a concept, they do not gloss over conceptual gaps. A single lesson plan in a class of learners with a diversity of ZADs is not adequate if teachers are to teach for understanding and retention. Each lesson should cater for at least three groups of learners identified on the basis of their prior understanding.

5.9.5 Assessment

If ICTs are used for teaching, it makes sense to use them in assessments, as supported by Tulving's encoding specificity theory. Literature shows the importance of building up concepts. It is my argument that assessments and tests should increase in both content and concepts as learners acquire new knowledge in order for the concepts to grow into 'blocks of blocks', mentioned in the retention metaphor in Section 2.2.1. Term 2 assessments should include Term 1; Term 3 should include Term 1 and 2; Term 4 should include Term 1, 2 and 3, so that learners do not forget what they have learnt. ICT tools are good intermediaries for keeping such records. The growth of a concept (Figure 5-2, according to this research's recommendation of levels of understanding, rather than grades that are based on a chronological consideration, should lead to a greater focus on the individual and not on a grade or class. Literature shows that ICT tools are well placed to individualise learning through a variety of affordances such as portability, accessibility, neutrality, feedback and appeal to a variety of learning styles.

If we are to teach for equity and not to satisfy bureaucratic requirements, learners should write differentiated tests that are based not on the number of years in school but the level of conceptual understanding in a subject and concept. Standardised tests, like prescribed pacing, are the biggest barriers to retention, because teachers are teaching the 'average' learner at the detriment of the very fast and slow achiever. One way of addressing this is to use ICTs to create multiple level tests on the same concept that allow every learner to experience a level of success in the mathematics classroom. This way, every learner has an opportunity to retain the concept at the level they understand it. Success breeds success.

5.9.6 Planning

Teachers should plan daily and individualise for each (category of) learner; the slow, the middle and the fast should be catered for. In an ideal situation, if schools are to enhance conceptual retention, planning should be at the level of each child. The teacher should ensure that they use media that caters for most learning styles as often as possible. Teachers need to find ways of ascertaining how learners best learn different topics, so that they emphasise certain styles over others, depending on the topic, particular concept or the learners being focussed on. The best technological medium followed by collaboration should be used to leverage the benefits associated with strong introductions and conclusions (primacy and recency). Every lesson should have a context that acts as a cue, and learners should be told in advance or exposed through technologies to the possible utility of learning a concept. The plan should include the tools used and for which indicator they are being used. Ideally, all indicators should be catered for during the teaching of every topic within a given time.

5.9.7 Feedback and Motivation

Marking verifies conceptual understanding and prior knowledge. Teachers should be up to date with marking, or where possible, use ICTs to expedite the process, although difficulties will arise when asking open-ended questions. The teacher should offer immediate feedback, at least before the next lesson to help both them and learners identify learning gaps. If the teacher cannot mark, they need to let the system do it for them. The interest component necessary to improve attitudes towards mathematics can easily be provided by gamified mathematics activities that certain applications offer in the form of athletics, a variety of games and other interesting contexts. The sustainability of external motivation in mathematics will require further exploration.

5.9.8 Contextualised Learning

Teachers should provide stimulating and real life contexts for learning. It will not be easy for any teacher to provide activities that are contextual, engaging and interesting in order to keep their learners busy all the time during the lesson, considering they also have to do marking and prepare lessons for the next day, but ICT can easily provide such contexts.

5.9.9 Catering for Different Learning Styles

Depending on learning styles, teachers should allow some learners to develop understanding through ICT, others through hard copies, and yet others through movement or practical work. Schools should do a lot of research to establish the learning preferences of children so they are not left out of the learning experience. The use of learning centres where learners rotate will allow learners to deal with the concept using different styles, including ones supported by ICT tools. Learning centres on the same topic but appealing to different learning styles should be set up in each class for learners to select the most appealing learning style for a topic or concept.

Teachers should never make any presumptions about how easy each child will find a topic. Their understanding is largely dependent on their prior knowledge, which varies from topic to topic and concept to concept. ICT tools and programmes that make it easy to quickly do a baseline test before a lesson, or even an activity, are important. Successful teachers will have to use data that identifies the strengths and weaknesses of each learner, bearing in mind that connections enhance retention and that no successful scaffolding process can happen without considering what learners can already do without assistance. The following (Figure 5-3) summarises elements that have featured in this research and make up the recommended framework. It has to be noted that most of the elements are repeated under different headings which is highly suggestive of their importance. The heading on the learner and retention have been deliberately omitted because if the framework is efficient, the learners' retention capacity should naturally be enhanced.

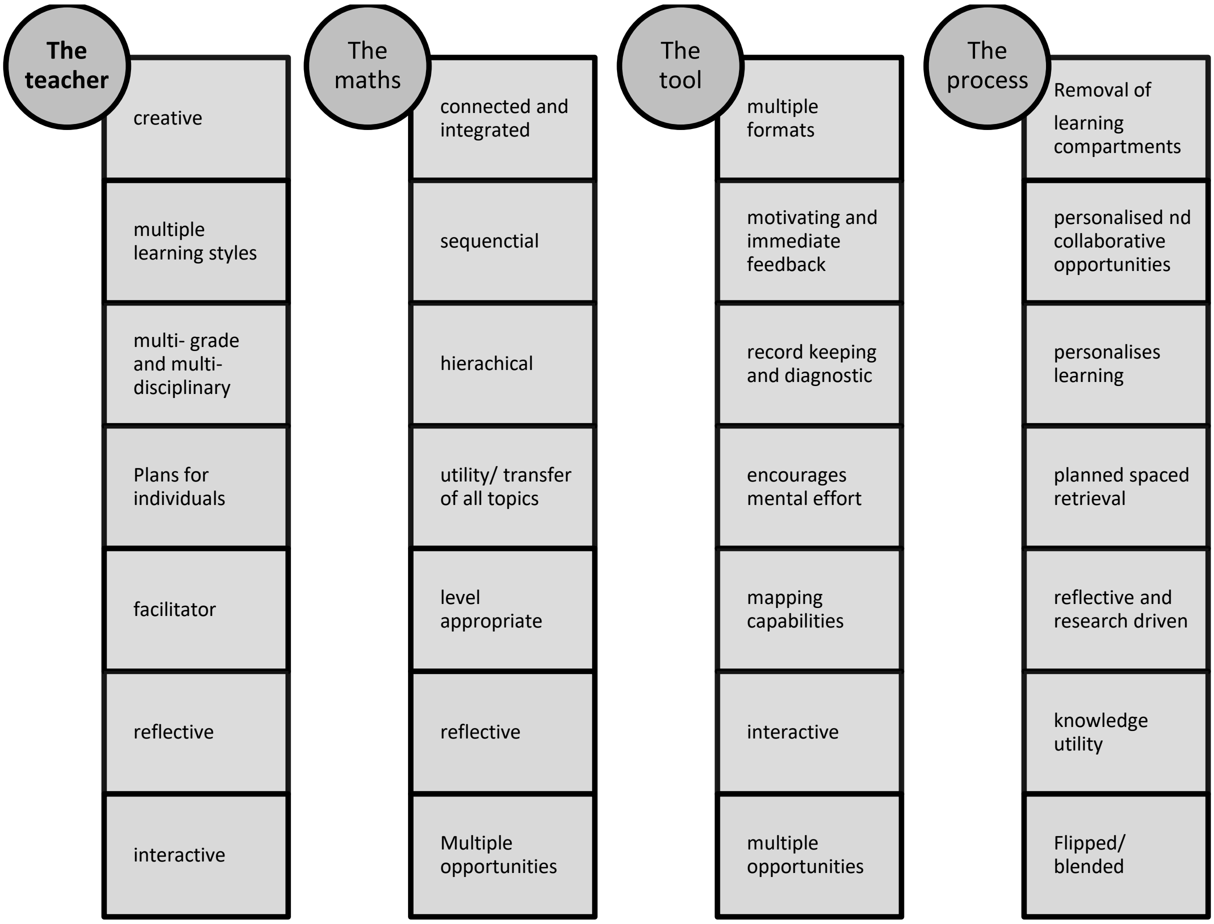

Figure 5-3 Summary of an enhanced pedagogical framework that altogether leads to retention of mathematical concepts showing the four crucial elements.

The four elements of an enhanced pedagogical framework (Figure 5-3) summarises the major issues raised in this study. The sub elements also feature prominently in the findings of this research. Effective implementation of the framework requires a lot of planning, data informed teaching and breaking of compartments within the learning system. This also requires the use of ICTs in the context of a creative and reflective teacher, connected and sequenced mathematics and an understanding of each learner's baseline knowledge and personalised learning plan reflected per concept, topic and the mathematics subject. The process also requires an understanding of which tools to use when teaching different concepts as well as the limitation of ICT tools in certain instances. The antithetical sub-elements of collaborative yet individualised learning, are possible if learners are grouped according to their individual understanding on a topic or concept. Such groups should not be permanent and will invariably change according to changes in learner understanding in different concepts, topics and subjects. Permanent ability groups might impede the future successful learning especially of low attaining learners.

CHAPTER 6: DISCUSSION AND RECOMMENDATIONS

Although the grounded theory approach is grounded on literature and data from selected documents, there is a variability of pedagogical contexts and the data is collected and analysed through subjective lenses, rendering certain findings difficult to entirely generalise. Having said that, the study should provide a reliable basis from which to undertake further experimental research on the topic. I also hope that the research will be informative to teachers, principals, policy makers, and hopefully, technological designers, so that ICT learning programmes can be deliberately structured to cater for affordances that have a direct bearing on indicators of retention that also reflect an awareness of the importance of hierarchy, connections and sequence. Finally, I hope that these findings have led to a pedagogical framework whose value is not restricted to the users of educational technologies only, but to all classroom practitioners who will have a deeper awareness of the nature of mathematics, the role of tools, as well as the need to teach in a manner that addresses the goals of learning as listed by Perkins (1991).

In conclusion, although it is tempting to assume that ICT tools immediately solve all mathematical problems, including that of retention, this research proves this is not the case. The role of good teachers and including other approaches and tools are still paramount because ICT tools are varied and incapable of solving every mathematical difficulty. Again, not every lesson or learner requires the use of ICT tools; hence, my view that schools should strive for blended learning rather than e-learning. Using the study to evaluate the no textbook drive in Gauteng and other provinces, I believe that while the motive is noble, the South African context is not yet ready for it. It takes a good teacher to make effective decisions on when to use textbooks and when not to do so. Having said that, ICT tools hold great potential to enhance retention in better ways than what good teachers will ever achieve alone and without them.

CHAPTER 7: CONCLUSION

This research makes the following recommendations regarding the effective use ICTs to enhance the retention of concepts based on the research findings. It must be noted that the main purpose of this research was the democratisation of mathematical education as well as changing the current difficulties faced in the subject.

Let us start with the basics of mathematics. It would be more suitable for the South African curriculum and practices to start with foundational knowledge and put emphasis on that until learners have a good grasp before teaching more complex concepts. The investment will pay off in the long run. Together with this, teachers should not blindly use ICT tools for every topic. In some instances, concrete objects will achieve better results, and more advanced learners will probably benefit a lot more from working in symbolic formats.

Secondly, besides the connections between concepts, there must be connections between grades and subjects. In an ideal situation, ICT tools would be used to create a theme in which several subjects and prior understandings can be used, and ICT tools would be used in schools where class, rather than grade teaching is promoted. Teachers should be encouraged to teach classes for more years than is currently the case. And just as people do not start building without the requisite resources, the teacher should take inventory of the skills and conceptual understanding required to succeed in a lesson. The role of baseline assessments in an ICT mediated classroom cannot be overemphasised.

Records play an important role in enhancing retention. A good tool is one that can be used easily to rehearse, space and connect concepts, and at the same time, keep records for each learner's performance. An evaluation on learner performance should not be for the whole topic but for micro steps within the concept. This will allow teachers to easily and quickly identify gaps in the conceptual understanding of learners and to intervene timeously.

The major impediments to teaching for understanding and retention seems to be prescriptive pacing and sequencing. These only serve a purpose for educational managers and administrators, and their lack of flexibility indicates that they are not learner centred or learner friendly. Competent teachers need the space to move at the pace of their learners. This will allow them an opportunity to apply all concepts and act as well as interact with them in connected and elaborative ways, thus promoting conceptual understanding and retention.

Schools should carefully select tools on the basis of whether they can allow learners to individualise learning and cater for the indicators of retention. Considerations of portability, distractions and user friendliness are important before schools invest a huge chunk of their resources in technologies.

Most importantly, technologies should have activities that cement (connect) prior concepts to current concepts and current concepts to future concepts. Each concept that has been taught and learnt effectively should have 'hooks' or 'tentacles' that connect to the previous concept and develop hooks that allow it to connect to the next concept. This requires careful planning and reflection by the teacher. For the process to occur successfully, teachers and learners need to depend extensively on the performance data that are readily available through ICTs.

The role of teachers in an ICT mediated classroom is that of a facilitator who supports learners in their own differentiated learning. This requires them to make daily use of system generated data to plan for each learner. Teachers need to invest more time in knowing their learners and what they can or cannot do in order to accurately structure personalised intervention programmes that help close learning gaps.

Assessment plays a huge role in retention, and ideally, it should be done by the teacher, who is aware of the levels of the learners being assessed. Assessments should be differentiated for each child, should reflect growth of a concept each time, and should be consistently spaced to enhance retention. In between, learners must get opportunities to practise and have multiple representations of concepts. The next important thing to remember is that all children are different. That difference has to be acknowledged in the way the teacher caters for different learning styles within the lesson. Teaching and assessments requires tailor-made processes that are not directed at the average learner but includes the slow, the average and the fast learner. Arguably, the most important task of teachers is identifying baseline competences of learners and designing an individualised learning plan that connects learners' baseline knowledge and skills to new learning experiences, followed or accompanied by practices that enhance retention of those concepts.

While it was not within the scope of this paper to have a deeper discussion on the goals of understanding and application, this research has illustrated in many ways the numerous links between the three goals. A simple framework for teaching mathematics should revolve around teaching for understanding and retention and making sure that each learning episode has opportunities for application. Although this can be done without ICT tools, the tools make the task easier, faster and more enjoyable.

In conclusion, the connected, sequential and hierarchical nature of mathematics requires it to be taught using a differentiated, learner-centric approach. This approach, as seen in the research, is supported by prior concepts that have to be available (retained). The needs of the learner and not those related to curriculum coverage must prevail. ICTs, if used correctly by a creative teacher, have a lot of potential to support both the retention of concepts and the differentiation currently lacking in the subject. Practices that erode differentiation in mathematics learning need to be done away with; this includes prescribed pacing.

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APPENDIX 2: SOFTWARE REVIEWS

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APPENDIX 3: TIMELINE

STEPS IN THE RESEARCH	DEADLINE FOR
1.Submission of proposal	20 May 2019
2.Design of the research plan	30 October 2019
4.Literature review	05 November 2019
5. Defining of a sample	10 November 2019
9. Coding of data onto the computer	20 November 2019
10.Raw tabulations/draft analysis of data	25 December 2019
11.Analysis of data	30 January 2019
12.Report up of findings	05 February 2020
13.Presentation of final research	25 February 2020
14. Final presentation of corrected copy for marking	10 July 2020

APPENDIX 4: ZIMBAWEAN LESSON PLAN

Grade 7 Mathematics lesson plan
Date : 14 June 2019
Topic : Area
Duration: 1 hour
Subject integration: SS, English, Science

Assumed knowledge:

1. Children can multiply
2. Children know the concept of space
3. Children know shapes.

Introduction

The teacher tells an interesting story about area

Lesson development

Step I: Demonstration

1. The teacher draws a shape on the board.
2. The teacher explains how to work out the area of the shape.

Imitation

1. Learners also calculate the area of a given shape on the board

Group work

1. Learners are given a variety of shapes to work in a group.
2. Learners find areas of shapes
3. Reportback

Individual work

Learner do an exercise on page 62 in the textbook

Conclusion

Giving children homework and checking for understanding

Evaluation

APPENDIX 5: GRADE 7 LESSON PLANS FROM SOUTH AFRICA

Mathematics Grade 7 Term 1

Topic:

1. Baseline assessment
2. Exponents

Week 1 and 2

Educator activities

1. Introducing the lesson
2. Linking topic to real life
3. Preparing resources
4. Facilitating group work
5. Checking for individual conceptual understanding
6. Marking individual work
7. Provision of homework

Learner activities

1. Participating in the lesson
2. Imitation of examples
3. Relating the topic to real life scenarios
4. Working in groups and collaborating to find solutions to provided problems
5. Writing individual class work
6. Writing homework
7. Assisting struggling fellow learners

Evaluation

1. Strengths

   ----

2. Weaknesses

   ----

3. Intervention

Mathematics Grade 7 Term 1

Topic:

1. Multiplication of fractions
2. Extension: division of fractions

Duration: 31-01-05-02-2019

Educator activities

1. Introducing the lesson
2. Linking topic to real life
3. Preparing resources
4. Facilitating group work
5. Checking for individual conceptual understanding
6. Marking individual work
7. Provision of homework

Learner activities

1. Participating in the lesson
2. Imitation of examples
3. Relating the topic to real life scenarios
4. Working in groups and collaborating to find solutions to provided problems
5. Writing individual class work
6. Writing homework
7. Assisting struggling fellow learners

Evaluation

1. Strengths

----

2. Weaknesses

----

3. Intervention

Mathematics Grade 7 Term 1

Topic:

1. Revision of work
2. Assessments and tests

Duration: 04-03-2019-15-03-2019

Educator activities

1. Introducing the lesson
2. Linking topic to real life
3. Preparing resources
4. Facilitating group work
5. Checking for individual conceptual understanding
6. Marking assessments and providing intervention
7. Provision assessments

Learner activities

1. Participating in the lesson
2. Imitation of examples
3. Relating the topic to real life scenarios
4. Working in groups and collaborating to find solutions to provided problems
5. Writing individual class work
6. Writing homework
7. Assisting struggling fellow learners

Evaluation

1. Strengths

   ----

2. Weaknesses

   ----

3. Intervention

APPENDIX 6: LESSON PLAN FROM KENYA

LESSON PLAN

GRADE 6

TOPIC: ADDITION OF FRACTIONS

DURATION: 10-21 JUNE 2020

INTROCUCTION

The teacher introduces the topic using concrete media

The teacher gives an example of how to add fractions

GROUP WORK

Learners solve problems on adding fractions as demonstrated by the teacher in groups.

Learners show others how they solved problems

LEARNER WORK

Children do work in the books

CONCLUSION

Marking of work done in the class

The teacher gives homework sheets

EVALUATION

APPENNDIX 7: GRADE 6 LESSON PLAN FROM SOUTH AFRICAN

GRADE 6 MATHEMATICS

NAME OF TEACHER

DURATION: 1 WEEK

CONTENT: FRACTIONS

CONTEXT: ADDITION OF FRACTIONS

MEDIA: CHALKBOARD

Teacher activities	Learner activities
1. Teacher demonstrates the concept 2. Teacher asks learners questions 3. Teacher give individual written work 4. Teacher marks 5. Teacher gives homework	1. Learners follow example by the teacher. 2. Learners demonstrate an understanding of the concept by working out on the board. 3. Learners write provided work 4. Learners do homework in books

REFLECTION--

GRADE 6 MATHEMATICS

NAME OF TEACHER

DURATION: 1 WEEK

CONTENT: SHAPES

CONTEXT: ADDITION OF FRACTIONS

MEDIA: CHALKBOARD

Teacher activities	Learner activities
1. Teacher demonstrates the concept 2. Teacher asks learners questions 3. Teacher give individual written work 4. Teacher marks 5. Teacher gives homework	1. Learners follow example by the teacher. 2. Learners demonstrate an understanding of the concept by working out on the board. 3. Learners write provided work 4. Learners do homework in books

REFLECTION--

APPENDIX 8: GRADE 3 LESSON PLANS

Term 4 Week 4 Date: 29-31/10-02/11/2018

Topics	Monday	Tuesday	Wednesday	Thursday	Friday	Assessment
Number Operations & Number concepts	Counting to 1000 B/F -Using a strategy of grouping for counting. -Know and write number names and symbols to 1 000. -Tr explains activities. -Learners work individually. Maths is Fun p.47	The counting strategy of grouping. -Estimating a number of objects. -Describe and order whole numbers to 1 000 and in order of size. - **FAT 1.** Multiplication to 100 by 2,5,3,4 and 10 in Assessment books. -Divide numbers to 99 by 2,3,4,5 and 10 -Money problems involving rands and cents. Convert between Rands and Cents.P145	Count forwards and backwards in multiples of25s,50s and 100s to 1 000. Identify and state the value of digits. **FAT 1** -Decomposing numbers. Orders and compares numbers up to 999. Unitary and Non-unitary fractions. ½,3/4,2/5,2/3. Maths is fun p 94 Platinum p.86	Estimating and checking on counting. **FAT I** Solving Word problems with addition and subtraction to 999. -Rounding off to the nearest 10. Division -Doubling and halving Building up and breaking down. -Rounding off Maths is Fun p 179	Practice number bonds to 30. -Mental sums **FAT 1** -Solve money problems involving equal sharing and grouping and remainders to 100. Mental Maths Card 133	
Patterns ,Functions & Algebra		Extend simple patterns with objects. -Create and describe own geometric patterns by repeating lines and shapes. -Tr explains. -Learners carry out the activities. Maths is fun p 38 and 49. Platinum p 76	**FAT 1.** Patterns counting in 1s,5s,25s ,50s and 100s between 0 and 1 000 B/F. -Learners count as a class and individually. -Written work.			

Gratton Primary School

Date: 22-26/10/2018 Week 3

Topics	Monday	Tuesday	Wednesday	Thursday	Friday	Assessment
Number Operations & Number concepts	Counting forwards and backwards to and from 1 000. -Using the strategy of grouping. -Using different problem solving techniques. -Tr lets learners solve problems in their favourite ways. -Feedback by learners individually.	Count F/B in 1s,2s,3s,4s to 1 000. Addition with answers to 900 using number lines and doubling and halving, building up and breaking –down methods and expanded notation. -Decomposing 3 Digit numbers to 850. -Questioning on methods and answers.	Describe, compare and order numbers to 1000., using smaller than, greater than and equals. Fractions—Recognises fractions in diagrammatic form. -Discussing about sharing and division. Doing practical activities on sharing, through cutting. -Showing fractions on diagrams.	Estimate objects and checking by counting and grouping.e.g. 463=100,50,100,200,1 0,1,1,1. -Place value: Know what each digit stands for. -Equivalent fractions -Learners work in groups and individually, giving examples and feedback.	Compare numbers to 500 with more or less -10 more than 223 =233 1 more than 322 =323. -South African coins and bank notes. -Money problems involving total and change. -Learners discuss problems in groups. Working out answers on paper. -Individual work.	
Patterns ,Functions & Algebra		Copy, Extend and Describe number sequence and patterns with numbers to 1 000. -Discussing the rule. Extend patterns in pairs, then individually.	Patterns counting in 1s- 10s,20s,25s,50s and 100s to 1 000 B/F. -Learners count in groups. -Writing answers in their pairs. Individual work.		Filling in missing numbers in number sequences individually.	

Topics	Monday	Tuesday	Wednesday	Thursday	Friday	Assessment
Number Operations & Number concepts	Counting to 1000 B/F -Using a strategy of grouping for counting. -Know and write number names and symbols to 1 000. -Tr explains activities. -Learners work individually. Maths is Fun p.47	The counting strategy of grouping. -Estimating a number of objects. -Describe and order whole numbers to 1 000 and in order of size. - **FAT 1.** Multiplication to 100 by 2,5,3,4 and 10 in Assessment books. -Divide numbers to 99 by 2,3,4,5 and 10 -Money problems involving rands and cents. Convert between Rands and Cents.P145	Count forwards and backwards in multiples of25s,50s and 100s to 1 000. Identify and state the value of digits. **FAT 1** -Decomposing numbers. Orders and compares numbers up to 999. Unitary and Non-unitary fractions. ½,3/4,2/5,2/3. Maths is fun p 94 Platinum p.86	Estimating and checking on counting. **FAT I** Solving Word problems with addition and subtraction to 999. -Rounding off to the nearest 10. Division -Doubling and halving Building up and breaking down. -Rounding off Maths is Fun p 179	Practice number bonds to 30. -Mental sums **FAT 1** -Solve money problems involving equal sharing and grouping and remainders to 100. Mental Maths Card 133	
Patterns ,Functions & Algebra		Extend simple patterns with objects. -Create and describe own geometric patterns by repeating lines and shapes. -Tr explains. -Learners carry out the activities. Maths is fun p 38 and 49. Platinum p 76	**FAT 1**. Patterns counting in 1s,5s,25s ,50s and 100s between 0 and 1 000 B/F. -Learners count as a class and individually. -Written work.			

Week 5 Date: 05-09 /11/2018

Topics	Monday	Tuesday	Wednesday	Thursday	Friday	Assessment
Number Operations & Number concepts	Counting to 1000 B/F -Using a strategy of grouping for counting. -Know and write number names and symbols to 1 000. -REVISION with the class ad groups work together. Maths is Fun p.139 -	The counting strategy of grouping. -Estimating a number of objects. -Describe and order whole numbers to 750 and in order of size. - Multiplication to 100 by 2,5,3,4 and 10. -Money problems involving rands and cents. Convert between Rands and Cents 203 -Tr explains sums and learners solve them.	Count forwards and backwards in multiples of25s,50s and 100s to 1 000. Identify and state the value of digits. -Decomposing numbers. Unitary and Non-unitary fractions. ½,3/4,2/5,2/3. -Demonstrating showing fractions and write the work. Maths is fun p 106 Platinum p.98	Estimating and checking on counting. Solving Word problems with addition and subtraction to 600. -Rounding off to the nearest 10. Division Maths is Fun p 145 -Rounding off in tens. Building and breaking down numbers, doubling and halving, number lines. -Show sums on number lines. -Reading word problems as a class and solve them, with discussions.	Practice number bonds to 30. -Mental sums -Solve money problems involving equal sharing and grouping and remainders. -Revising and marking the work. Mental Maths Card 132	
Patterns ,Functions & Algebra		Extend simple patterns with objects. -Create and describe own geometric patterns by repeating lines and shapes. -Learners follow instructions to make patterns. Maths is fun p 103. Platinum p119	. Patterns counting in 1s ,2s,3s,4s,5s and 100s to 1 000 B/F. -Learners count in groups and individually. -Class presentation.			

APPENDIX 9: PHOTO CLIPS

APPENDIX 10: GRADE 2, 3 AND 9 SUMMARY MARK SHEETS

Results per Grade/Subject
2019/07/15

Year: 2019, Term: 2 - 2019/04/02 - 2019/06/14, Grade: 3, Gender: All
All Learners

Grade 3		Number of learners in each achievement rating							No of Absent and Non-complete	Total Numbers o Learners
Subject	% Average Mark	Level 1 0 - 29.99	Level 2 30 - 39.99	Level 3 40 - 49.99	Level 4 50 - 59.99	Level 5 60 - 69.99	Level 6 70 - 79.99	Level 7 80 - 100		
Afrikaans First Additional Language (Gr 03)	80.33					5	7	15		27
English Home Language (Gr 03)	75.48			1	1	7	5	13		27
IsiZulu First Additional Language (Gr 03)	68.33	1	4	1	2	6	1	12		27
Life Skills (Gr 03)	79.48					2	15	10		27
Mathematics (Gr 03)	75.63				2	7	8	10		27

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Results per Grade/Subject
2019/07/15

Year: 2019, Term: 2 - 2019/04/02 - 2019/06/14, Grade: 2, Gender: All
All Learners

Grade 2		Number of learners in each achievement rating							No of Absent and Non-complete	Total Numbers of Learners
	% Average	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7		
Subject	Mark	0 - 29.99	30 - 39.99	40 - 49.99	50 - 59.99	60 - 69.99	70 - 79.99	80 - 100		
Afrikaans First Additional Language (Gr 02)	84.40				1	2	5	22		30
English Home Language (Gr 02)	61.00			4	12	8	5	1		30
IsiZulu First Additional Language (Gr 02)	62.77	1	1	6	6	4	6	6		30
Life Skills (Gr 02)	77.77					6	12	12		30
* Mathematics (Gr 02)	66.00			3	11	4	4	8		30

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APPENDIX 11: GRADE 9 MARK SHEET

Results per Grade/Subject
2019/07/15

Year: 2019, Term: 2 - 2019/04/02 - 2019/06/14, Grade: 9, Gender: All

Grade 9		Number of learners in each achievement rating							No of Absent and Non-complete	Total Numbers of Learners
Subject	% Average Mark	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7		
		0 - 29.99	30 - 39.99	40 - 49.99	50 - 59.99	60 - 69.99	70 - 79.99	80 - 100		
Afrikaans First Additional Language (Gr 09)	46.00		4	1	2	2				9
Creative Arts (Gr 09)	78.14		1		4	7	5	34		51
Economic Management Sciences (Gr 09)	59.65			1	24	22	4			51
English Home Language (Gr 09)	74.71				1	17	15	18		51
IsiZulu First Additional Language (Gr 09)	64.29	1	1	8	7	5	13	7		42
Life Orientation (Gr 09)	63.00			5	15	20	11			51
Mathematics (Gr 09)	52.86	3	8	14	8	9	6	3		51
Natural Sciences (Gr 09)	61.55			5	17	20	7	2		51
Social Sciences (Gr 09)	68.16		3	6	8	10	11	13		51
Technology (Gr 09)	57.27	10		1	4	16	15	5		51

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APPENDIX 12: GRADE 7 MARK SHEET IN SOUTH AFRICA

		TERM 4 MATHS						TERM 4 EMS					
No.	Surname, Name (Alphabetically)	DATA COLLECTION PRO		ASSIGNMENT INTERG		MATHEMATICS TEST		EMS TEST			Rating	Rating
		30		30		34		50	150		1-7	1-7
1		23		19		18		20				
2		21		25		24		40				
3		23		22		10		29				
4		24		19		16		16				
5		17		15		16		18				
6		25		25		22		34				
7		23		18		16		13				
8		23		28		28		12				
9		25		28		32		41				
10		23		15		26		20				
11		23		14		10		16				
12		23		18		18		16				
13		16		20		26		12				
14		15		17		4		17				
15		23		24		14		23				
16		15		20		20		23				
17		21		28		18		18				
18		24		27		0		23				
19		23		19		15		33				
20		21		8		13		31				
21		24		11		15		14				
22		23		19		13		11				
23		23		22		19		29				
24		23		13		19		21				
25		18		23		8		16				
26		25		30		33		38				
27		23		26		28		25				
28		16		19		34		12				
29		18		25		16		21				
30		24		27				23				
31		23		30		25		35				
32		18		18		10		14				
34		23		14		21		25				
35		23		27		22		39				
36		25		19		22		30				
37		18		14		20		13				
38		17		13		12		15				
39		20		24				24				

	DATE	SIGN	DATE	SIGN	
EDUCATOR:					
PRINCIPAL/HOD:					
CLUSTER COORDINATOR:					

APPENDIX 14: PROOFREADING CERTIFICATE

WORDPLAY EDITING
Copy Editor and Proofreader
Email: karien.hurter@gmail.com
Tel: 071 104 9484
Website: http://wordplayediting.net/

To Whom It May Concern:

This letter is to confirm that the research proposal *The Missing Link: How ICTs Contribute to Retention of Mathematical Concepts. A Conceptual Study* by Benson Munyoro was edited by a professional language practitioner.

Regards,

Karien Hurter