SCHOOL OF PSYCHOLOGICAL SCIENCES & HEALTH

University of Strathclyde
Humanities & Social Sciences

DEVELOPING WORKING MEMORY AND NUMERACY SKILLS IN PRIMARY-AGED SCHOOL PUPILS BY COMPUTERISED TRAINING PROGRAMMES: THE EFFECTIVENESS OF ADAPTIVE MULTI-DOMAIN WORKING MEMORY TRAINING

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A thesis presented in part-fulfilment of the requirement for the Award of Doctorate in Educational Psychology

July 2017

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Declaration of authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

Word count: 49608

Dedication

This thesis is lovingly dedicated to my Mum, Mary Brown, nee McInally (1944 – 2016).

My Mum's gifts of love, beauty, laughter, courage and prayers will forever shine down and around me. She dedicated her whole self to me and sacrificed so very much to invest in my education and development. All that I am is because of my Mum. There has never been anyone greater.

My Mum deserves a daughter who loves her and has a good memory. She got one!

Acknowledgements

My deepest gratitude is owed to my supervisor, Professor Jim Boyle, who is a deeply committed researcher and mentor. His expertise, support, patience, encouragement and wisdom, are forever a beacon of inspiration and clarity. I believe I learned from the best.

Appreciation is extended to my second supervisor, Professor Lisa Woolfson, and also to Dr Marc Obonsawin for their insightful comments during progress review meetings and on my thesis.

Since joining South Ayrshire Council Educational Psychology Service six months ago, I have been incredibly nurtured with this study, and extend a deep thank you to Jacqui Ward, Principal Educational Psychologist, and the team.

Encouragement from friends and time for ‘giggles’ continue to be a source of happiness, thank you.

I am also very grateful to the children and school staff involved in this study.

ABSTRACT

Systematic reviews indicate that while working memory training programmes may yield ‘near-transfer’ effects with improved scores on measures of working memory, there is less convincing evidence for ‘far-transfer’ effects generalising to academic skills. This thesis aims to further investigate training-transfer effects by evaluation of two computerised training programmes to develop working memory and numeracy in primary school-aged pupils. Three studies are reported. The first is a quasi-experimental design comparing effects upon 7-8 year old pupils of a 7-week computerised working memory training programme Memory Quest Flex (Junior) (Truedsson & Strohmayer, 2010) (*n*=25) with a 7-week computerised numeracy training programme Study Ladder (Study Ladder Holdings Ltd., 2013) (*n*=27), both relative to a non-active control condition receiving their regular curriculum (*n*=24). The computerised numeracy training programme served as both treatment and active control conditions, to control for the Hawthorne Effect. Training-transfer effects are measured using performance scores on dependent variables of working memory, fluid reasoning and numeracy, and independent variables of treatment condition, time-point and gender. Children’s scores on the Pupil’s Perceptions of Numeracy Questionnaire (PPNQ), a short scale developed for this study, were considered to illuminate findings of the main study.

Findings from the main study change score analysis revealed the adaptive computerised working memory training programme yielded significant near-transfer effects to a complex working memory task, [$F(2,73) = 13.9$, $p < .001$, $\eta_p^2 = .28$], with Cohen’s *d* +1.34 relative to other conditions. Significant transfer effects were reported for fluid reasoning, [$F(2, 73) = 31.6$, $p < .001$, $\eta_p^2 = .46$], with Cohen’s *d*

+1.34 relative to other conditions, and numeracy performance, [$F(2, 73) = 4.63$, $p = .013$, $\eta_p^2 = .11$], with Cohen's d + .65, relative to the control condition. However, Study Ladder yielded only near-transfer effects to numeracy performance, with Cohen's d + .56, that approached conventional significance levels ($p = .053$). No significant main effect was found for gender across conditions for any dependent variables (all p-values > .251).

In the second study, Principal Components Analysis confirmed the PPNQ had a unidimensional structure and good internal consistency reliability (Cronbach's $a = .806$). Findings revealed a positive shift in PPNQ scores following intervention in understanding numeracy instruction. Findings for the control condition support conclusions that the PPNQ was sufficiently sensitive to detect increasingly negative perceptions of numeracy. This study suggests how the PPNQ might be used to identify children's perceptions of numeracy and access to the numeracy curriculum.

The third study used qualitative methods to investigate issues of implementation fidelity important for acceptability and feasibility of computerised training programmes in the primary schools.

This thesis identifies dual benefits of adaptive, multi-domain computerised working memory training not fully explained by the Hawthorne Effect. Recommendations are discussed towards the development of a computerised working memory training paradigm in schools.

Key Words: working memory, computerised training, numeracy, implementation fidelity

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CHAPTER 1: INTRODUCTION

This study is concerned with numeracy and working memory. The two aims of this study are to: evaluate the effectiveness of two commercial computerised training programmes to improve numeracy and working memory in primary-aged school pupils, and secondly, explore the feasibility and acceptability of both programmes in the primary school context.

Numeracy is a fundamental skill important for lifelong learning, yet attainment levels reported in the recent Scottish Survey of Literacy and Numeracy (Scottish Qualification Authority, 2013), and local data indicate concerns. Chapter 1 presents some reasons for this in the literature, which relate to the vulnerability of numeracy to negative self-perceptions and other psychosocial factors; although these are compounded by difficulties reaching a consensus definition of numeracy. Evidence-informed school approaches to numeracy reported in the literature include multi-sensory pedagogical approaches (Williams, 2008), distributed practice with interleaved learning and spacing (Cepeda, Pashler, Vul, Wixted & Rohrer, 2006; Rohrer, 2012); and the use of computer technology for experimental learning (Wilson & Dehaene, 2007). Both, developmental stage models (Butterworth, 1999; 2005; Dehaene, 1997) and cognitive processing models (Bull, Espy & Weibe, 2008) of numeracy development are explored in the literature as a means to understand children's numeracy development and performance.

This thesis proposes that numeracy development and its individual differences are more fully understood by the most current frameworks of executive functions, which include working memory (Diamond, 2013), since numeracy and working memory share a unique variance (Alloway & Passolunghi, 2011; Raghubar, Barnes & Hecht, 2010). Executive functions are described in the literature as a central, cognitive suite that allows us to flexibly adapt and regulate our behaviours towards personal goals across the lifespan (Cowan, 2005; Diamond, 2013). Cognitive flexibility is a central marker of executive function, and relates directly to working memory since working memory processes are characterised by switching, generating and processing information (Anderson, 2002, Cowan, 2005, Diamond, 2013).

Working memory is defined in the literature as a valuable on-line system that stores, manipulates and processes information, and which is capacity- and time-limited (Apter, 2012; Bayliss, Jarrold, Baddeley, Gunn and Leigh, 2005). Theories of working memory are considered further in Chapter 2, with the revised multi-component model (Baddeley, 1986; 2001; Baddeley & Hitch, 1974; 1994; Baddeley & Logie, 1999) selected in this study since it is the most empirically validated model of working memory to date. Further, the model has been used to explore relationships between working memory and educational attainment (Alloway, 2006; Alloway & Alloway, 2010; Söderqvist & Bergman Nutley, 2015), with particular note in this study to numeracy attainment (Dumontheil & Klingberg, 2012; Geary & Hoard, 2005; Nyroos & Wiklund-Hörnqvist, 2011).

However, differences in individual performance on measures of working memory are not fully accommodated by this model. Recent studies now conceptualise working memory processes within broader neural networks, or executive functions. The multi-modal model of executive functions proposed by Diamond (2013) is selected for this study since it offers particular promise to educational contexts. Diamond

(2013) embeds working memory within executive functions; which demonstrate the neuroplasticity of the brain and malleability of working memory to training improvement, which offer potential for raising educational attainment.

Next, literature studies of computerised training as an approach to improving working memory and numeracy are discussed, and candidate training programmes proposed. Systematic reviews indicate that while working memory training programmes may yield ‘near-transfer’ effects resulting in improved scores on measures of working memory, evidence for ‘far-transfer’ effects to more general academic skills, in areas such as numeracy, is more challenging to specify (Melby-Lervag & Hulme, 2013; Shipstead, Redick & Engle, 2012). This led in turn to incorporating a computerised training programme in numeracy in this study as a control condition to deal with possible ‘Hawthorne effects’ (McCarney et al. 2007). Recent research studies also identify implementation issues with computerised training programmes which merit further analysis in this study (Alloway, Bibile & Lau, 2013; Morrison & Chein, 2011; Shipstead et al. 2013).

At the outset, it is helpful to orientate the reader with the next section, which aims to provide details of the epistemology and overarching theoretical perspectives that underpin this study.

1.1 OVERARCHING THEORETICAL PERSPECTIVES

1.1.1 Universal versus targeted interventions

The Standards in Scottish Schools Act etc. (2000) places a duty on educators to meet the needs of all children in all education settings. The author proposes that the focus of this thesis resonates with the Act since it offers the prospect of improving all children's attainment and quality of life. Hence, research designs that align with a universal framework for intervention are attractive prospects for any local authority. Universal or core interventions are the foundation provided for all children to promote positive learning, or other outcomes, as part of a staged model of interventions displayed in Figure 1 below (Otten & Tuttle, 2010). The staged model of intervention proposes that effective universal supports should be sufficiently robust to meet the needs of most children (Sugai, Horner & Gresham, 2002), with fewer children subsequently requiring intensive, targeted supports indicated at the apex of the triangle in Figure 1.

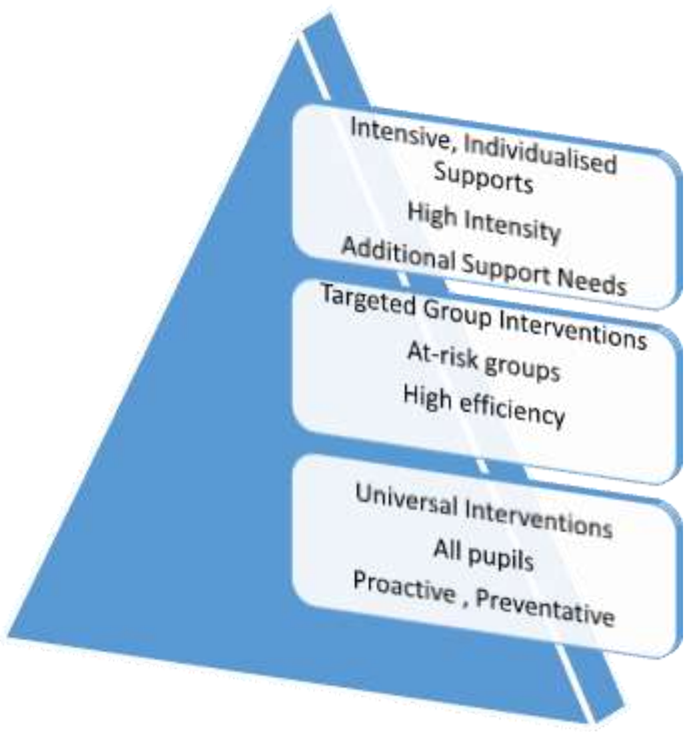

Figure 1: A staged multi-tiered model of intervention programmes (Otten & Tuttle, 2010)

Universal interventions are widely evaluated within paradigms of evidence-based practice (Fullan, 2007; Greenberg, Domitrovich, Graczyk & Zins, 2005). Notwithstanding the importance of research outcomes, there is a noticeable call by many researchers for a shift to implementation science paradigms which are concerned with the challenge of measuring process variables important for successful, evidence-informed interventions (Dane & Schneider, 1998; Frederickson, 2002; Kelly, Woolfson & Boyle, 2017; Lendrum & Humphrey, 2012; Weissberg, Kumpfer & Seligman, 2003).

1.1.2 Quality implementation of interventions

For the purpose of this study of the evaluation of computerised training programmes, it is important to define what implementation science is before considering the specific features pertinent to effective implementation of interventions. Implementation science is concerned with three features: (a) whether an intervention is adopted, (b) the process of how an intervention is implemented in the setting, and, (c) whether the intervention is sustainable over the longer-term (Kelly & Perkins, 2012). Extensive data from meta-analyses of successful implementation of interventions indicate that the process of implementation is significantly related to achieved outcomes (Durlak &DuPre, 2008).

Fixsen, Naoom, Blasé & Friedman (2005) provide a helpful ecological and interactionist model to describe the components of successful implementation (see Figure 2). The model proposes that implementation is influenced by the integration of three main drivers that include organisational components, competency drivers and leadership, represented in Figure 2. In highly desirable contexts, these drivers integrate and facilitate each other to deliver positive outcomes for service-users, represented by bottom-up arrows in the diagram.

Figure 2: Illustration of Fixsen et al.'s (2005) framework for effective implementation of interventions

Guldbrandsson's (2008) Criteria for Implementation Checklist translates the components of the Fixsen et al. (2005) framework into a practical checklist for research-practitioners to guide intervention planning to determine intervention suitability, and whether the wider context is amenable to intervention. Kelly & Perkins (2012) extended the components of effective implementation illustrated in Figure 2 to create an implementation checklist to support intervention planning in school contexts and was selected for use in this study to determine initial needs and drivers of schools (see Appendix A).

1.1.3 Implementation fidelity in schools

Implementation fidelity, or how effective an intervention is implemented, is particularly important in local authority school settings, since schools, as organisations, often struggle to implement quality interventions (Fullan, 2007). For example, schools can be resistant to accepting new interventions because of a lack of time to facilitate their administration, which in turn may be further impacted by diminishing resources. As a result of these challenges or risks, it is crucial that the features of implementation fidelity are understood to be met from the outset of this study. This section now turns to elaborate on six fundamental components of implementation emphasised in the literature for successful implementation, which include: adherence, dosage response, quality of programme delivery, participant response and the programme's reach and differentiation from other programmes (Dane & Schneider, 1998; Durlak & DuPre, 2008), and which are shown in Figure 3.

Figure 3: Illustration of the components for implementation fidelity (Durlak & DuPre, 2008).

A primary concern for successful implementation is programme fidelity, or adherence as it is sometimes referred (Durlak & DuPre, 2008), which denotes the extent to which the programme in practice adheres to the original programme. This is not easily achieved when considering some of the challenges inherent in school settings described above. Oftentimes, adherence is not reported in computerised training studies, but is recommended more recently (Shwaighofer, Fischer & Buhner, 2015).

Dose response refers to the relationship between dosage (or the frequency with which the interventions should be delivered to demonstrate positive outcomes) and the magnitude of the observed effects of the intervention (Kelly & Perkins, 2012). Experimental studies of computerised WM training programmes (Gathercole, 2014; Melby-Lervag et al. 2013; Shipstead et al. 2012) suggest that when specific dosage thresholds are met, learning retention is evidenced to different contexts; with specific dosage thresholds being associated with observed effect sizes (Schmidt & Lee, 1988). However, further research would be required to investigate the effects of different levels of dosage, which is beyond the scope of this study (see Chapter 3 for a review of the training literature). Programme dosage considers the level of the original programme that is delivered in practice. For example, the frequency and duration of computerised training sessions over the implementation phase should be explicit to determine programme dosage (Morrison & Chein, 2011).

An important feature of implementation fidelity outlined in Figure 3 is that the selected programme is different to other related programmes. Programme differentiation is important for the validation of research findings, and to identify any causal relationship between the intervention and observed outcomes. When reviewing a candidate programme, the reach of a programme should also be stipulated at the outset to establish that participants are those the programme is intended for. For example, making reference to Figure 1, there are different levels of need within a staged intervention approach, and similarly, programmes must be selected according to the identified needs to be met; whether the programme is intended as universal or targeted supports. Finally, the response of participants is important to determine whether the intervention is acceptable and feasible for implementation.

1.2 THESIS OUTLINE

The other chapters of this study comprise: Chapter 2 which presents a definition for understanding numeracy and evidence of the nature of numeracy difficulties at local and national level. Reasons for this difficulty are proposed, and concern the vulnerabilities of numeracy performance to broad ecological factors. The elements of effective numeracy programmes are considered, which elaborate on multi-sensory approaches and computer technology. Next, theoretical frameworks of numeracy development are discussed, with evidence indicating the importance of working memory in numeracy development and performance. The chapter concludes with a summary of the research.

Chapter 3 reviews the theoretical frameworks of working memory and expands on the revised multi-component model of working memory to explore working memory and its relationship with numeracy development. Other perspectives on working memory will be considered. However, emphasis is placed on current perspectives

that situate working memory within a broader framework of executive functions, which accommodates individual differences and the evidence from neuroscience studies on the neuroplasticity of the brain and malleability of working memory capacity. How working memory might be measured is also considered. The chapter concludes with a review of how working memory is thought to develop in children.
Chapter 4 considers the possibilities for education by computerised learning programmes, before reviewing key features of games-based learning within broader theories of learning and motivation. A framework for evaluating games-based learning programmes is considered. An expanded review of computerised working memory training studies follows, and the inherent challenges of implementation variables are synthesised to provide some understanding of the underlying mechanisms of training-transfer effects. Looking at what computerised training programmes are currently available for children, two candidate programmes already available in the local authority in which the study takes place merit further evaluation. Concluding remarks are provided from the literature review.

Chapter 5 presents the rationale for the selected research design and research questions. A critique of methodological issues is presented to inform selection of methodologies for each of the three studies which comprise this thesis. An overview of the methodology and instrumentation of each study is described, followed by the rationale for the data collection and analysis strategy.

Chapters 6, 7 and 8 present the procedures and findings of Study 1, 2 and 3 respectively.

Chapter 9 concludes with a discussion of the main research findings and implications for future directions.

CHAPTER 2: CHILDREN'S NUMERACY ATTAINMENT

2.1 INTRODUCTION AND CHAPTER OUTLINE

This chapter has three main purposes: firstly, to place this study in the literature of numeracy attainment and numeracy development; secondly, to unpack the nature of individual differences in numeracy performance by understanding underlying processes of numeracy; and thirdly, to identify the key elements of school numeracy programmes. This chapter is divided into five sections. The first section puts forward a definition of numeracy, outlining its relationship to mathematics. The second section explores the importance of numeracy for lifelong learning against the backdrop of worrying national and local trends of poor attainment in schools. The next section offers a closer look at some of the key factors from the literature which impact upon numeracy. The fourth section elaborates on the main school curriculum approaches to numeracy. In the final section, an interactionist framework is proposed for understanding numeracy development, which examines the issues surrounding developmental stage models of numeracy and the value of cognitive processing models which account for individual differences in numeracy development and attainment.

2.2 DEFINING NUMERACY

In the face of evidence demonstrating the importance of numeracy for future life chances and the myriad of factors that impact on numeracy performance, it is surprising there remains ambiguity about defining numeracy; and how it relates to mathematics, or otherwise. The definition of numeracy reflected in the Curriculum for Excellence or CfE (SEED, 2004) is practical, relating to life experiences:

Numeracy is a vital skill that is important in everyday life. It is about being confident when solving problems, making decisions and analysing situations that involve numbers. Numeracy is key to lifelong learning.
(CfE Factfile Series 3: Numeracy across Learning, 2004).

The CfE (2004) recognises that to make learners numerate, experiences must be woven through a range of aspects of learning and life experiences. However, there is a danger that this definition of numeracy may be interpreted too simplistically, in the sense that numeracy is synonymous with the 'basics' of mathematics, or four operations of number (i.e. addition, subtraction, multiplication and division). Therefore, it is necessary to unpack key definitions of numeracy.

International definitions of numeracy make the distinction between numeracy and mathematics, holding that numeracy is a proficiency with numbers across contexts usually acquired from being taught mathematics (Australian National Numeracy Advisory Panel, 2008; Hernandez-Martinez & Williams, 2013). Particularly noteworthy, are those more recent understandings of numeracy below that highlight its underpinning and interconnection with higher-order cognitive processes, or executive functions (EF), such as reasoning, recall and problem-solving. In fact, numeracy is becoming synonymous with reasoning skills:
Numeracy describes the set of skills needed to tackle real-world problems in a variety of situations by applying numerical reasoning in order to plan how to solve the problem, and then carry out the mathematical procedures to find the solution.
(Welsh Government, 2013a, p. 20.)

Clearly, explanations of being numerate reflect a shift to illustrate vital elements of EF such as problem-solving and reasoning:

Numerical reasoning is the process of using 'number sense' (i.e. knowing when to use a particular operation; when to use mathematics relationships; ability to monitor one's performance when computing, as example, judging reasonableness of answer with respect to an applied problem or by what one knows about numbers) which facilitates the formation of conclusions, judgements, or inferences from facts or premises in order to tack real-world mathematical problems in a variety of situations.

(National Numeracy, 2014, p. 2.)

The role of EF (which will be discussed in detail in the next chapter) in numeracy skills are increasingly recognised as an important feature of effective numeracy curriculum programmes. For example, Ofsted (2008) in their inspection of 192 English schools identified that opportunities to apply and utilise EF, inherent within numeracy and information technology, are not fully operationalised in many numeracy curriculum programmes.

2.3 THE IMPORTANCE OF NUMERACY FOR LIFE-LONG LEARNING

Good numeracy is the best protection against unemployment, low wages and poor health (Andreas Schleicher, OECD, 2013).

Numeracy is one of the 'big three' pillars for learning, alongside literacy, health and wellbeing (Donaldson, 2011; National Numeracy Strategy, Scottish Government, 2011). Being numerate offers more than proficiency with numbers; it offers valuable transferable skills ranked amongst the top skills by employers (Davies, Gore, Shury, Vivian, Winterbotham & Constable, 2012). However, investment in research studies on numeracy development and evidence-informed numeracy interventions, have been under-resourced in comparison to the investment literacy has attracted, both in the UK and internationally (Graham, Bellert & Pegg, 2007; Swanson & Jerman, 2006).

2.3.1 Why should we be concerned?

It is perhaps surprising that numeracy is recognised as an important life-skill, yet some 6% of pupils in mainstream education show evidence of serious numeracy difficulties, and 25% of pupils with identified learning difficulties struggle with numeracy (Cass, Cates, Smith & Jackson, 2003). Results from a recent Scottish Survey of Literacy and Numeracy (SSLN) (Scottish Qualification Authority, 2013) identify the need for early intervention in numeracy to tackle the evident 'holes' in primary-aged children's numerical skills, which widen significantly as pupils' transition to secondary school. While, national surveys and strategies identify broad trends and 'holes', their findings are often too broad (Stiggins & Chappuis, 2005). Subsequently, local authorities are charged with operationalising the national strategy to improve numeracy attainment outcomes. This study aims to support the home local authority respond to the challenge.

A current priority for the local authority where the author is employed as an educational psychologist (EP) is to enable all children and young people to master aspects of numeracy as basic life skills through experiential learning that engages learners and continuously enhances their numerical skills throughout education. The local authority is one of three national Numeracy Hubs and strives to develop evidence-informed pedagogy in numeracy through its partnership with the National Numeracy Strategy (Scottish Government, 2011). Local baseline assessment of numeracy levels in children at the end of Primary 1 is shown in Figure 4.

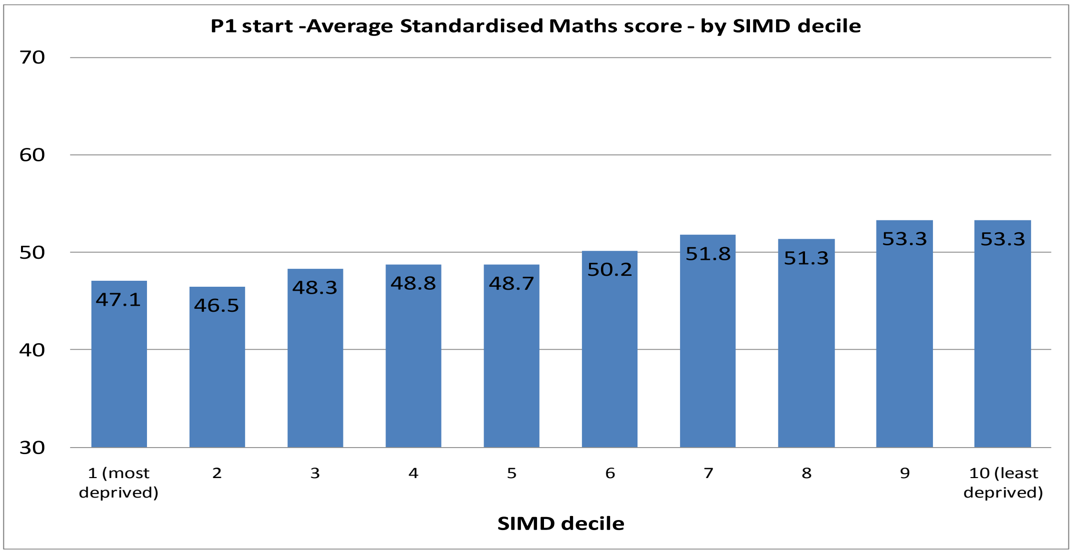

Figure 4: Local authority Primary 1 average standardised maths score across Scottish Index of Multiple Deprivation deciles

From Figure 4, a score of 50 on the standardised assessment used represents an age-appropriate level of attainment. This is achieved in schools with more advantaged catchment areas, but there is concern about the impact of deprivation, indicated by the lower Scottish Index of Multiple Deprivation (SIMD) (Scottish Government, 2012) deciles upon achievement in numeracy in the early stages, as Figure 4 reveals.

2.3.2 Children's perceptions of numeracy

With the recognised need to improve numeracy attainment hitherto discussed, qualitative studies of perceptions of numeracy across the age ranges and social messages from the media indicate numeracy is generally viewed as difficult to understand, or only accessible to intelligent or even gifted people (Epstein, Mendick & Moreau, 2010). Older school children, students and adults were the focus of later research (Dowker, Bennet & Smith, 2012). When considering those early studies of younger children's perceptions of numeracy, younger children relate positive perceptions and attitudes to numeracy, which become increasingly negative with age (Blatchford, 1996; Wigfield & Meece, 1988). Studies indicate that pupils' negative perceptions of numeracy may arise when they experience early difficulties understanding procedures and concepts, and without success, increasingly poor motivation and negative perceptions of numeracy emerge (Gilbertson, Witt, Duhon & Dufrene, 2008).

A taxonomy devised from a review of the literature shows key factors impacting on children's perceptions of numeracy and is outlined in Table 1, and thereafter is discussed with reference to the research studies.

Table 1

Taxonomy of factors important to children's perceptions and attitudes to numeracy

Level	Factors
Individual child	Psychosocial reactions (Ashcraft, 2002; Ashcraft & Krause, 2007; Chinn, 2012; DeCorte. Greer & Verschaffel, 1996) Attitudes (Krinzinger, Kaufmann & Willmes, 2009) Executive functions (Ashcraft et al. 2007; Haase, Júlio-Costa, Pinheiro-Chagas, Oliveira., Micheli & Wood, 2012) Motivation (Gilbertson, Witt, Duhon & Dufrene, 2008)
Social Environment	Social messages from family and media (Epstein, Mendick & Moreau, 2010) Evidence of peer support network (Mata, Monteiro & Peixoto, 2012)
Curriculum	Practical transfer to real world problems (Fuchs, Fuchs, Powell, Seethaler, Cirino & Fletcher, 2008) Performance (Gilbertson et al., 2008)
Pedagogy	Instruction (Cuttance, 1998; Mata et al., 2012) Language of numeracy (Lazarides & Ittel, 2012)

An area which has attracted research interest is children's psychosocial responses to numeracy (Ashcraft, 2002; Ashcraft & Krause, 2007; Chinn, 2012; DeCorte, Greer & Verschaffel, 1996). 'Maths anxiety', or feelings of anxiety towards numeracy, has attracted considerable research and suggests that children (and adults, including teachers) may feel anxious about numeracy, leading them to avoid it (Hembree, 1990). More recent studies with younger children aged between 6-9 years conclude a relationship between children's numeracy performance and self-ratings of their abilities (Krinzinger, Kaufmann & Willmes, 2009; Thomas and Dowker, 2000).

Interestingly, Mazzocco & Kover's (2007) longitudinal study of primary-aged children provides evidence that their expressed attitudes towards numeracy can predict later numeracy performance. These studies are consistent with the work of Carol Dweck which proposes that having the belief of progress, or a 'growth mindset' leads to success, not solely talent (Dweck, 2008; Henderson & Dweck, 1990).

Additionally, individual factors, such as a child's cognitive processes, or executive functions (EF), in particular working memory, may also impact on the psychosocial response to numeracy. For example, Ashcraft et al. (2007) suggests that poor working memory impacts on numeracy performance, which may be confounded by negative self-perceptions of numeracy which in turn, overload working memory capacity, thus impacting on numeracy performance. Later studies posit that while EF, specifically working memory, do impact performance, a child's attitude towards numeracy and their self-perceptions of performance are powerful factors in numeracy attainment and represent an enduring challenge to resolve (Haase et al. 2012).

Attempts to investigate the factors involved in children's perceptions were the focus of Mata, Monteiro & Peixoto's (2012) study with Portuguese children. While it is possible that cultural differences limit any transferable conclusions, of interest from the structural equation modelling applied are those motivational variables as strongest predictors of attitudes towards numeracy, with support of the class teacher and peer group as mediating variables. Interestingly, the relationship between younger children's attitudes to numeracy and their perceptions of the teacher's instruction and understanding of the language used, has attracted few studies to date, albeit a direct relationship has been found in secondary-aged pupils (Lazarides & Ittel, 2012). The classroom setting and wider school environment are also thought to have an important role in children's perceptions of numeracy (Cuttance, 1998).

2.4 OVERVIEW OF NUMERACY APPROACHES IN SCHOOLS

Unsurprisingly, the diverse definitions of numeracy and many ecological variables impacting on numeracy performance make a core curriculum difficult to specify. An overview of the current literature on numeracy interventions included meta-analyses and some smaller scale international studies to identify pedagogical approaches, techniques and curriculum resources of effective numeracy curriculum programmes. Key aspects of effective school numeracy approaches are summarised in Table 2 below.

Table 2

A summary of elements of effective numeracy approaches in schools[1]

Elements of effective numeracy approaches for school pupils
Systematic instruction to develop a repertoire of numerical concepts, procedures and skills
Systematic instruction of the language of numeracy, both written and verbal language communication
Learning objectives and outcomes communicated clearly at the start of activities
Practice and consolidation to develop fluidity of numeracy
Sequential learning opportunities that scaffold, link with and build upon prior learning
Opportunities to link numerical procedures, concepts and skills within and across contexts and cross-curricular projects to activate higher-order executive functions
Real world problems selected to develop continuous challenge through enquiry
Multi-sensory and computerised learning are embedded in daily curriculum programmes to encourage broad representations of numeracy and problem-solving
Learning activities that require pupils to explicitly explain and defend problem-solving strategies and conceptual understandings
Flexible groupings of all pupils to encourage explicit sharing of the language of numeracy

The next section expands upon the main approaches found in the literature which include: multi-sensory pedagogical approaches, cross-curricular experiential learning, computer technology and interleaved learning approaches.

2.4.1 Multi-sensory pedagogical numeracy approaches

Multi-sensory pedagogical approaches emerged from early education methods, influenced in particular by Montessori (1946) and John Dewey (1966), who viewed learning as a participatory experience, and not solely a process of imparting

[1] Key elements are summarised from: Ainley & Doig, 2001; Anthony & Walshaw, 2007; Askew, Brown, Rhodes, Johnson & Wiliam, 1997; Australian National Numeracy Advisory Panel, 2008; DiGisi & Fleming, 2005; Hernandez-Martinez & Williams, 2013; Ofsted, 2008; Sousa, 2014; Wadlington & Wadlington, 2008.

knowledge to children. Multi-sensory approaches are characterised by connecting the learning activity through the use of more than one sensory modality (Preston, 1998). For example, using visual materials with combined auditory stimuli. Multi-sensory approaches are based on the premise that by harnessing multiple senses during a learning activity, components of working memory are summoned that aid recall for future learning (Carbo, Dunn & Dunn, 1986; Lyons, 2003). Some support for this perspective is found in neuroscience studies (Mousavi, Low & Sweller, 1995). Further, proponents of the approach suggest that effective learning is mediated by the opportunities afforded for compensatory learning strategies, with say, auditory and kinaesthetic modalities compensating for weak visual modalities, and that active use of all modalities supports representation of the learning activity (Moustafa, 1999). Evidence suggests that modality preference develops with maturation; with early childhood learning characterised by kinaesthetic or tactile modalities, and stages from middle primary school onwards characterised by visual and auditory modality preferences (Moustafa, 1999).

The Williams Review (Williams, 2008) was a major piece of public research commissioned to provide evidence on current practices in numeracy and mathematics education in Britain. The Review (*op cit)* aimed to share recommendations to raise standards in initial teacher training, early years' settings and early intervention approaches for pupils struggling to make progress in numeracy. The scope of the review was extensive, with evidence gathered using mixed methodologies, including summarised international and national research findings, public engagement exercises with the teaching profession, including face-to-face and written consultations with 100 head teachers and 200 class teachers in primary and early year settings across England, Scotland and Hungary. The review also encompassed public and written consultations with parents and children. Unfortunately, secondary schools were not included in the review, which limits the salience and generalisability of recommendations across educational contexts. The Williams Review and other studies (Askew et al. 1997; Fuson, 1992) identify multi-sensory approaches as hallmarks of effective numeracy programmes. Guidance from research advises that teachers provide teaching and learning opportunities that incorporate at least three modalities (i.e. visual, auditory and kinaesthetic) for optimal learning experiences and outcomes (Gadt-Johnson & Price, 2000). However, despite the increasing use of these approaches in education, Moats & Farrell (2005) in their seminal text reviewing the evidence-base, indicate there remains a lack of conclusive evidence from converging fields to confidently demonstrate the efficacy of multi-sensory learning experiences (Carreker, 2006; Moats & Farrell, 2005).

Turning now to a core subset of multi-sensory approaches, is the concrete-to-abstract strategy (Kamina & Iyer, 2009; McNeil and Jarvin, 2007; Sousa, 2014). Here, concrete materials and apparatus, or manipulatives, are used to introduce and explore numerical procedures to encourage transfer of procedural knowledge (concrete) to conceptual understandings (abstract) across contexts (Bryant, 1995; Rittle-Johnson, Siegler & Alibali, 2001). Several researchers identify caveats in selection and delivery of the concrete-to-abstract strategy which highlight that not all children consistently transfer learning between concrete-to-abstract experiences (Dowker, 2004; Fuson, 1992; Hannell, 2013). For example, McNeil & Jarvin (2007) identify that to develop understanding and memory, educators must perceive concrete-to-abstract manipulatives as relevant to the numeracy concepts being learned, and not just 'toys' for fun. In practical terms, some children may not always see the connections between concrete materials, such as a number line and the real-world problem. Initially educators provide valuable scaffolding or explicit instruction on the use of manipulatives to develop the child's level of symbolic representation (Boulton-Lewis, Wilss & Mitch, 1996; Olson & Truxaw, 2009). With mastery, best practices encourage educators to then provide graded exploration opportunities where manipulatives can be used creatively (Knewstubb & Bond, 2009), and finally learning opportunities are planned that promote abstraction i.e. children are encouraged to explore many possible solutions to problems (Loughran, 2009).

Despite the widespread use of multi-sensory approaches in education, current research is required to determine the most effective methods of using a multi-sensory approach for teaching and learning. Further, comparisons between different multi-sensory approaches, and their impact on children's performance in different curriculum subjects, and for children with a range of different learning needs, would be helpful to educators (Dowker, 2004; McNeil, Uttal, Jarvin & Sternberg, 2007; Williams, 2008).

2.4.2 Cross-curricular numeracy experiences

A second widely recognised principle of effective numeracy interventions and programmes is the cross-curricular teaching and learning approach (Gick & Holyoak, 1983). The approach is based on the premise that for effective learning to take place, learning has to be applied across a plethora of contexts, in the classroom and real-world experiences. Cross-curricular approaches to numeracy also provide a compensatory learning strategy so that children who struggle in one context are offered opportunities to access numeracy experiences in another, which in turn supports the development of multiple representations of numeracy (Maddux, Johnson & Willis, 2001). Clearly, there is overlap between multi-sensory approaches and cross-curricular learning opportunities, with numeracy materials and experiences being offered across a variety of contexts (Gick & Holyoak, 1983). Consistent with this view is the findings of a case study analysis of effective teaching practices of ninety class teachers across 11 schools by Askew et al. (1997). Primary teachers were identified as effective practitioners based on pupils' learning progress over the academic year. A bespoke numeracy test was developed to measure pupil progress. Mixed methods included: questionnaires, intensive interviews and observations of teaching practice. Interviews with head teachers over two terms identified their beliefs about the nature of numeracy and how pupils become numerate. The pedagogy of numeracy was explored with a small sample of ninety teachers across 11 schools. Pupils were also asked to reflect on similar age appropriate questions. While a small-scale case study design, and concentrated on primary schools in England may limit generalisable conclusions, the robust triangulation of rich datasets provides insightful conclusions about effective numeracy teaching. For example, the study identified the most effective teachers who raised numeracy attainment as 'connectionists'. Distinctions in their practice indicate their use of direct instruction of numeracy procedures, alongside the development of pupils' awareness of connections in their knowledge, skills and conceptual understanding. Positive outcomes meant pupils of 'connectionist' teachers were more flexible in their numerical problem-solving approaches, both in familiar and novel contexts.

2.4.3 Computer-based numeracy approaches

Various sources detailed in the previous sections of this chapter highlight that children's numeracy development improves if learning opportunities combine at least three learning modalities (Mousavi et al. 1995; Gadt-Johnson et al. 2000) and numeracy attainment improves if the learning is perceived as meaningful to real-world situations through cross-curricular projects and manipulatives. Increasingly, real-world contexts involve the use of digital technology (Zevenbergen, 2011).

Research evidence indicates that information technology or computer-based programmes are effective for learning (Boyle, Connolly, Hainey & Boyle, 2012; Mayer, 2003) and a meta-analysis study by Kulik (Kulik & Kulik, 1991; Kulik, 1994) of computerised numeracy training programmes report improved numeracy attainment with an average effect size of .47 with elementary school pupils. Computerised training programmes also offer motivational learning experiences through repetitive practice and are optimal learning levels adapted to individual learners' needs; all of which may partially account for improvements in numeracy performance (Aminifar, 2007; Drijvers & Weigand, 2010; National Council of Teachers of Mathematics, 2000; Schoppek & Tulis, 2010). A study by Takahashi (2000) highlights the value of computer instantiated manipulatives (CIM) as an alternative to concrete manipulatives in numerical problem-solving. The study investigated differences in numerical problem-solving in 9-10-year-old American school children (N = 18). Children were asked to find as many of 18 possible solutions to cover an equilateral triangle using three blue and three green pattern blocks. Half the children worked in small groups of three with concrete manipulatives, which allowed for rich peer problem-solving strategies as opposed to individual problem-solving; and the other half of children worked independently on the computer using software to solve the problem. Results showed that those children working on computers found more solutions, and spent more time on task before giving up, relative to the other group. Although the study had a small sample size and extracted the children from the whole class setting in small groups, findings suggest that the use of computers as a concrete manipulative holds promise in supporting primary school-aged children to develop multiple representations of numeracy problems, leading to longer periods of sustained engagement with the numeracy problems and improved performance outcomes. A future study could explore the use of CIM and its implementation in the busy classroom setting.

Shults (2000) compared traditional didactic instruction (the control condition) to computer-based instruction (the treatment condition) for sixteen pupils aged 6-7 years old and found no significant difference when comparing the mean percentile scores with t-tests comparisons. Limitations of the study include the small sample size. However, pupils' motivation for the software was a moderator of numeracy outcomes, and worthy of careful consideration in future research. Other research studies build upon the view that computer-based learning is a powerful medium for strengthening links between procedural knowledge and conceptual understanding which is a fundamental process during numeracy development (an overview of numeracy development is considered in the next section), and provides an invaluable enrichment to the role of the class teacher (Al-Musawi, 2007; Kroesbergen & van Luit, 2003; Rauscher et al. 2016; Williams, 2008; Wilson & Dehaene, 2007). Indeed, the National Council of Teachers of Mathematics (2000) conclude that computer technology should be incorporated into numeracy curricular programmes as a concrete material.

Other research studies of the use of computer-based numeracy programmes suggest this approach may be successful since it provides multi-sensory representations of numeracy problems that facilitate the ability to generate possible solutions using procedural knowledge and conceptual understanding, and subsequent transfer to novel contexts (Rittle-Johnson et al. 2001; Shrager & Siegler, 1998). Hence, computer-based learning in numeracy programmes may support children to represent number (Butterworth & Laurillard, 2010; Rauscher et al. 2016). Butterworth & Laurillard (2010) found that accurate numerical procedures were facilitated by representational supports (i.e. prompts or visual highlighters), problem-solving experience and feedback; all of which are features of computer-based learning programmes (see Chapter 3 for discussion of computer-based learning). Munn (2001) identified that computer-based approaches to numeracy instruction provide key opportunities for learners to test and validate their conceptual understanding of number rules, especially in the early years of education. However, more evaluation studies are required to determine the value-added of computerised numeracy programmes in primary school settings with typically developing children (Al-Musawi, 2007; Drijvers & Weigand, 2010; Geiger, Goos & Dole, 2013), particularly as evaluative studies to date comprise small sample sizes (Butterwort & Laurillard, 2010; Rasanen, Saminen, Wilson, Aunio & Dehaene, 2009) and study designs limited to comparisons with untrained, or non-active control groups (Kucian et al. 2011; Rasanen et al. 2009).

2.4.4 Interleaved learning practice

Insight into factors that enhance retrieval and transfer of information for learning was the focus of an early study by Baddeley and Longman (1979) of the training schedule of British postal staff when learning a new keyboard procedure. Some of the staff learned the new skills in spaced-training sessions interspersed across time, while others learned the new skills in massed-training sessions, where training sessions were concentrated and immediately followed each other. Results showed that the group receiving the spaced-sessions outperformed the massed-session staff in keyboard skills, which provides some evidence that how information is presented i.e. spaced learning sessions, is more conducive to efficient learning.

Another popular approach to the teaching and learning of numeracy in education is interleaved learning. Interleaved learning is illustrated in Figure 5 to demonstrate that as an approach, it ensures that the amount of practice devoted to a particular skill is spaced or distributed across multiple episodes (separated by intervening tasks).

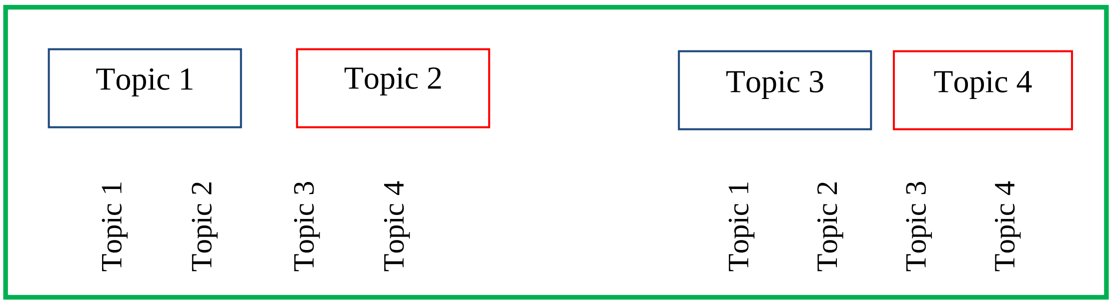

Figure 5: Illustration of interleaved learning

Taylor & Rohrer's (2010) study was the first to assess whether the positive gains reported for interleaved learning approaches reflect conflated effects of conjoint interleaving and spacing, especially since the spacing effect, as already described, is a robust effect in research studies of learning (Cepeda et al. 2006). Taylor and Rohrer (*op cit*) tested this hypothesis with 24 children aged between 10-11 years old, who were randomly assigned to the interleaved or massed learning conditions. Children were taught to solve numeracy problems in a practice session and a test session one day later. Findings suggest the interleaving practice condition impaired practice performance, yet these difficulties proved worthwhile as interleaved learning contributed to higher test performance. Review of the effects suggest that interleaved learning requires learners to switch between tasks more than massed practice, and so benefits learners' discrimination of appropriate instructions, procedures or concepts, and boosts associations made between problems and the process of finding solutions. Further studies could assess whether these positive effects for interleaved learning practices generalise to other materials and concepts beyond numeracy.

2.5 A TRANSACTIONAL FRAMEWORK FOR NUMERACY DEVELOPMENT

Numeracy is a complex skill involving a range of cognitive processes or executive functions (EFs). This section considers those EFs thought to be important for numeracy, outlining the major theoretical models, namely developmental stage and cognitive processing models. The role of EFs in numeracy development will be introduced here, but detailed in Chapter 3.

2.5.1 Developmental stage models of numeracy development

Research studies point to innate or 'hardwired' principles of numeracy development which are evident in infants (Butterworth, 2005). Studies with infants in the first few weeks of life suggest their grasp of 'numerosity' (Butterworth, 1999; Dehaene, 1997;

Devlin, 2000); a number sense, or conceptual awareness to make distinctions between the number of distinct items in a set long before language and logical understandings emerge. For example, infants can discriminate between differing sets of objects and are able to identify when smaller number sets change, either by adding or subtracting items in the set (Wynn, 1992). It is important to interpret these results with caution since the infants may be responding merely to cues in their visual environment. It is more widely accepted that it is not until children are aged between 4-6 years old that they rely less on visual perception cues, and demonstrate genuine 'numerosity' (Bryant, 1995).

Early perspectives on numeracy considered it a universal development across all children which followed a sequential process of development (Bryant, 1995). Stages of development proposed by Piaget (Wadsworth, 2004) offer an early stage model of numeracy development as a unitary process that develops as the child interacts with the environment. While Piaget's early developmental stage model accommodates aspects of higher-order thinking, or EFs, such as reasoning and attention, his was essentially a developmental stage model since the EF processes underpinning numeracy development have more recently been researched (Bull et al. 2008; Swanson & Beeb-Frankenburger, 2004). Piaget posited a 'four stage' model of development, illustrated in Figure 6, which is widely held today and places the foundations of numeracy and reasoning at the heart of child development.

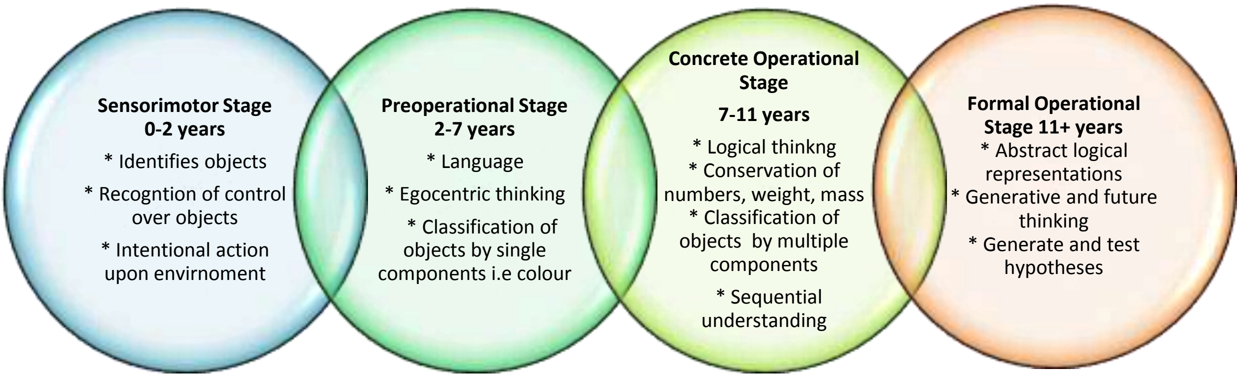

Figure 6: Piaget's model of child development

Note: Ages for the developmental stages should be interpreted as broad estimates of development

During the early stages of numeracy development, termed the 'preoperational stage', children begin to recognise the features of objects and classify items in a set by a single component such as colour or size. As highlighted in the previous section, children require concrete and multi-sensory materials to represent and understand their world. During play, children act upon these materials to support their early understanding of number, object properties and the language of number (Bryant, 1995; Hughes, 1986).

Next, the child moves onto the exploratory 'concrete operational stage', whereby concrete materials become increasingly valuable for demonstrating and representing procedural knowledge in numeracy. More recently, Ritter-Johnson et al. (2001) identify procedural knowledge as the ability to follow a known strategy or routine to solve problems, which utilises specialised knowledge to tackle specific types of problems, thus is context-limited. During this stage, the child's readiness for number is marked by the process of 'reversibility', or ability to perceive a change and simultaneously override the change. 'Reversibility' is considered a core developmental milestone central to one-to-one correspondence, seriation and conservation of numbers. It is thus a foundational skill underpinning cardinal and ordinal counting properties, and recognising additive properties of numbers, multiplication, division and measurement, in that order. Piaget's work focused less on the value of contextual supports for mastery or learning generally, and more on the child as an independent learner. Worthy of note are studies that emphasise the value of contextual supports in children's mastery of numeracy, and which highlight that with contextual supports, children can demonstrate earlier and greater understanding of numeracy, including numerical operations (Boulton-Lewis et al. 1996) and sharing and fractions (Paley, 1981). These studies have important implications for education today, when considering the 'value-added' by the team around the child, and the specific learning resources and approaches selected to enrich the numeracy experiences for children as detailed earlier in this chapter.

The 'concrete operational stage' is a crucial stage since it facilitates emergent conceptual understanding of numeracy. Again, Ritter-Johnson et al. (2001) propose conceptual knowledge is a generative and transferrable knowledge of the overacting principles which can be used in novel problems across contexts. Within developmental stage models, counting is one of the earliest numeracy skills to emerge during the 'preoperational stage', being observed in children as early as 2 years old. However, the number words for counting are inconsistent at this early age, to the extent children may be merely practising using number names (Bryant, 1995). Learning to count with meaning and some accuracy is noted within the 'concrete operational stage', and serves to facilitate later stages of development, with counting accuracy developing simultaneously with procedural knowledge (i.e. knowledge of the hierarchical structure of numbers based on decades, tens, hundreds and thousands) and later conceptual skills relating to the language of numbers (i.e. irregular number words) (Gelman, Meck & Merkin, 1986). A review of studies on children's counting as outlined by Bryant (1995) locates counting within the early concrete operational stage, emerging around the pre-school years of education when children have some understanding of the cardinal and ordinal properties of number, to then later meaningfully understand the quantitative value of number words and language of numeracy (Bryant, 1995; Butterworth, 2005).

Finally, the child enters the 'formal operational stage' by way of an interdependent, 'hand-over-hand process', facilitated by procedural knowledge and concrete learning opportunities (Ritter-Johnson et al. 2001). From 11 years old, emergent abstract operational thinking supports the development of repertoires of numeracy procedures and conceptual knowledge, including recall of digit facts from memory and access to efficient and fluent counting (Butterworth, Marchesini & Girelli, 2003). It may also be that conceptual knowledge used to retrieve procedural knowledge strengthens the memory pathway and improves recall (Anderson, 2002). It has been suggested that gains in procedural knowledge may free up attentional resources which children can then use towards conceptual processes, including planning, to transfer knowledge and reasoning across contexts (Shrager & Siegler, 19980.

While the stages of the developmental model often overlap with each other, gaps or difficulties at one stage affect performance and development at another. However, these gaps or difficulties can also be observed independently of each other. For example, different children display different and daily inconsistencies in numeracy performance (Dowker, 2004; Houssart, 2007). As discussed in the earlier sections of this chapter, numeracy performance is influenced by individual difference in EF development, and is particularly vulnerable to many factors, especially children's self-perceptions of numeracy performance. Borst, Poirel, Pineau, Cassotti & Houdé (2012) propose that Piaget's tests may underestimate children's underlying development since test performance also relies on a child being able to inhibit inaccurate responses to demonstrate their abilities in a test scenario. Indeed, inhibitory control is an EF young children often do not acquire until later (see Chapter 3 for further details on executive functions). A constraint of the developmental stage model is the hierarchical structure, which conflicts with individual inconsistencies in numeracy performance. A child may perform less well at apparently easier numeracy tasks (i.e. counting), while performing very well on more abstract or difficult tasks (i.e. word fraction problems). Therefore, components of the stages of development may inform foundations for learning, yet they are not always linear in development. Several studies reviewed by Denvir & Brown (1986) suggest that it is not possible to establish an absolute stage model of numeracy development whereby one component precedes the other.

A penultimate point is emphasised by seminal research (Donaldson, 1978; McGarrigle & Donaldson, 1974) which highlights the influence of a child's context and cultural experiences on numeracy development; a construct not clearly apparent in Piaget's developmental stage model (Wadsworth, 2004). Specifically, how learning experiences are shared and encouraged with the child in their role as 'apprentice' rather than solitary 'scientist', and how the child then synthesises the information they learn to understand and act upon their environment (Rogoff, 1990).

Finally, Carraher, Carraher & Schliermann's (1985) seminal study demonstrates the impact of the environment on numeracy proficiency in Brazilian market stall children whose numerical skills were significantly more accurate and flexible using mental maths than formal algorithms, the latter having minimal utility in the market stalls of Brazil.

2.5.2 Cognitive processing models of numeracy development

Cognitive models of numeracy investigate the processing that underpins numeracy tasks. The literature identifies a number of EF including attention, working memory, processing speed and fluid reasoning that underpin numeracy development (Bull, Espy & Wiebe, 2008; Butterworth, 1999; Diamond & Lee, 2011; Gathercole & Pickering, 2000b; St. Clair-Thompson & Gathercole, 2006). The role of these EFs in numeracy varies across the age range (DeSmedt, et al. 2009), with younger children relying on visuospatial cues to solve numeracy problems (Li & Geary, 2013), whilst older children make greater use of their understandings of language to solve numerical problems (DeSmedt et al. 2009). Evidence from neuroscience on the development of children with dyscalculia, a specific learning difficulty in numeracy, provides further insight into the relationship between EFs and numeracy development and the important role working memory has in this relationship (Swanson & Beebe-Frankenberger, 2004). Several studies investigating the nature of gaps in numeracy attainment suggest these gaps include difficulties with:

- access to and retrieval of numeracy or counting strategies
- word problem-solving
- accuracy and speed of recall

(Bryant, Bryant & Hammill, 2000; Gifford, 2005; Russell and Ginsburg, 1984).

Of particular relevance to this study are research findings indicating that working memory (see Chapter 3) is the strongest predictor of numeracy performance in the early to middle primary school years (Alloway & Passolunghi, 2011; Bull et al. 2008; Hitch & McAuley, 1991; Van der Ven, Kroesbergen & Leseman, 2011). While the exact nature of this relationship is less clear (Halberda, Mazzocco & Feigenson, 2008), children who excel in early numeracy have greater working memory capacity (McLean & Hitch, 1999, Passolunghi, Mammarella & Altoe, 2008). Early progress in number is in turn a strong predictor of subsequent progress (Alloway & Passolunghi, 2011; Butterworth, 2005; Dehaene, 1997).

Although some general conclusions about the importance of EFs in numeracy development may be drawn from these studies, the role of working memory in numeracy is slightly more difficult to specify. For example, Trbovich & LeFevre (2003) found that adjusting the format (vertical versus horizontal presentations) of numeracy problems led to the recruitment of different working memory processes. In addition, while some studies have indicated that working memory provides a unique contribution to numeracy proficiency during the school-age years (Bull & Scerif, 2001), Espy et al. (2004) reported that the contributions of working memory might overlap significantly with other EFs in the preschool years. This may be due to a greater need to recruit generalised EF skills during the initial stages of learning, compared to perhaps more specific EF skills required in more complex tasks as the child matures (Espy et al. 2004; DeStefano & LeFevre, 2004). Moreover, studies have shown that children over the age of 7 years old rely on working memory less for simplistic numeracy tasks such as single-digit calculations, compared to more complex operations such as equations (Ashcraft & Kirk, 2001) and solving mathematical word problems (Geary, 2004; Passolunghi & Siegel, 2001). Evidence of the unique shared variance between working memory and numeracy also comes from studies of children experiencing numeracy difficulties and is discussed more fully in the next chapter. Children struggling with numeracy have been recommended support in the development of their working memory to promote retention and recall of concepts and skills (Kroesbergen, Van Luit & Naglieri (2003). However, research by Naglieri & Johnson (2000) adds further weight to the relationships between numeracy and EFs since these researchers contend that the impact of numeracy interventions varies with the children's cognitive profile, particularly for those pupils with poorer planning skills.

As stated previously, cognitive models explore the processes underpinning numeracy which accommodates individual differences in numeracy performance and in turn have greater practical utility to supporting children experiencing numeracy difficulty. Interventions to enhance working memory capacity and numeracy attainment may have implications not only for improved attainment outcomes, but also for educational instruction and curriculum design.

2.6 SUMMARY

Strong evidence has been presented that numeracy is a crucial life skill that allows individuals to contribute to their communities, albeit school attainment levels remain a concern in the UK. A review of the literature highlights effective numeracy approaches to raise numeracy attainment, including multi-sensory methods and the use of cross-contextual learning opportunities, supported by computer-based learning.

Both the developmental stage models and cognitive processing models have influenced our understanding of numeracy development and performance. These models converge on two important points. Firstly, on the key components of numeracy development that include counting, recall of numerical facts, understanding concepts, and the ability to follow procedures. The second area both models converge is the complementary process that underpins those key components; the concrete and procedural knowledge of numeracy operations and the abstract conceptual understanding of those numeracy operations across different contexts or problems. This reciprocal relationship is crucial for optimal learning and progression in numeracy.

Difficulties accounting for individual differences in numeracy performance are informed by current theories of EFs which underlie numeracy development. Specifically working memory has particular relevance in numeracy development and attainment from many converging sources, including experimental, educational and factor analytic studies of typically developing children and adults, and studies of children with numeracy difficulties. Developing children's working memory has been the focus of more recent studies as a means of promoting retention and recall of numerical procedures and conceptual understandings. The next chapter expands on the theoretical frameworks of working memory to understand its role in learning, and numeracy. Further studies are reviewed which purport to improve working memory in children and yield gains in attainment.

CHAPTER 3: WORKING MEMORY

3.1 INTRODUCTION AND CHAPTER OUTLINE

The aim of this chapter is to provide an overview of the major theories of working memory and to review the research literature with regard to the role of working memory in children's attainment and how best to improve working memory capacity. This chapter first considers the significant cognitive theoretical perspectives on working memory, in particular the revised multi-component model of working memory offered by Baddeley and colleagues (see Baddeley, 2007 for an overview). The second section considers the evidence of working memory development in children and the challenge of accounting for individual differences when performing educational tasks that require access to the working memory system, which this study proposes are not accounted for by Baddeley, 1986, 2001; 2007; Baddeley & Hitch, 1974; Baddeley & Logie, 1999). A third section provides a summary of two main models of EF, before elaborating on Diamond's (2013) model which embeds working memory within broader EF networks, and acknowledges its vulnerability for measurement. Section four explores the various dilemmas of measurement, and directions are gleaned from the research literature for future studies. In the final section, the challenges and issues of improving working memory are summarised and a possible candidate intervention for improving working memory capacity is suggested.

3.2 MODELS OF WORKING MEMORY

The term 'working memory' (WM) has been used over the last four decades to describe an active, limited-capacity and time-limited memory system responsible for storage, manipulation and processing of information (Apter, 2012; Bayliss et al.

2005). Significantly, in the meta-analysis by Melby-Lervag & Hulme, (2013), WM is described as: *"one of the most influential theoretical constructs in cognitive psychology"* (Melby-Lervag et al. 2013, p. 270). These definitions of WM are informed by the processes of storage and attention.

Some research studies have emphasised the processing and storage components of WM. As WM is time- and capacity-limited, there are constraints on the resources that can be shared between storage or processing demands (Daneman & Carpenter, 1980; Engle, Cantor & Carullo, 1992). Later research by Towse & Hitch (1995) and Hitch, Towse & Hutton (2001) posits WM as an active system of 'trade-and-switch' between storage and processing of information. They argue that individuals switch between storage and processing to reduce the time information is held in storage, since time is the crucial factor that can cause information to be forgotten or lost due to the process of decay; all of which may occur when attentional resources are diverted. Expanding on mechanisms underpinning storage and processing functions, Barrouillet, Bernardin & Camos (2004) propose that both the time needed to hold attention, and the cognitive load of the task influence WM capacity.

Theories of WM also make connections with important higher-level cognitive processes, such as attention, indicating that WM processes have a key role in orientating attention (Kane, Bleckley, Conway & Engle, 2001). This is a significant function of WM, since attentional control is required in all aspects of human cognition, from identifying a goal, maintaining it by selecting important information to attend to, and equally inhibiting attending to irrelevant interferences, and ultimately achieving the goal (Kane et al. 2001). Evidence for this model comes from studies indicating that participants with high memory span are able to control and resist interference, displaying retention and processing of more information, relative to participants with low memory span (Kane et al. 2001).

Important to note is the model of WM proposed and developed by Nelson Cowan which makes direct links between WM and the EF of attention (Cowan, 1999, 2001, 2005). For Cowan, WM is activated through a process of focusing attention towards new information and information already held in longer-term memory. Mechanisms of focusing attention contribute to performance on a range of WM tasks, and are shown to develop with maturation (Cowan et al. 2005). He proposes that attention processes can access all information that is in conscious awareness. However, as attention processes are capacity-limited, only information that is activated by the focus of attention to a sufficient threshold enters conscious awareness. Consequently, this information is held in reserve, so to speak, and can be moved in or out of conscious awareness depending on contextual demands. Finally, information not activated by the focus of attention remains in WM and may be retrieved if there are pertinent retrieval cues, such as verbal rehearsal or grouping/chunking strategies which develop with age (Cowan et al. 2005).

3.2.1 The revised multi-component model of working memory

The revised Baddeley and Hitch multi-component model of WM (Baddeley & Hitch, 1974; Baddeley, 2001; 2007) provides the theoretical framework for the present study for two reasons:

- the model is sufficiently comprehensive to distinguish between the modality used in memory and the effects of skill-level and strategy use (LeFevre, DeStefano, Coleman & Shanahan, 2005);
- it provides a good fit to WM data from children (Gathercole, Pickering, Ambridge & Wearing, 2004), including the age range 4-11 years, a key maturational stage for the development of WM components (Anderson, 2002; Davidson, Amso, Anderson & Diamond, 2006).

An overview of the model is provided in Figure 7 and described in more detail below.

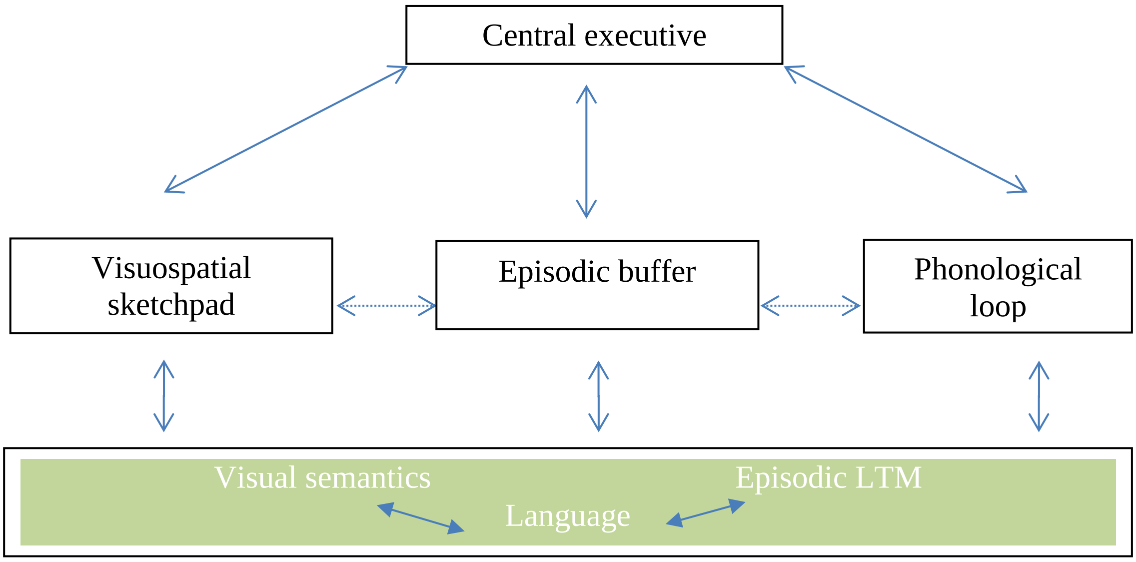

Figure 7: The revised multi-component model of WM (adapted from Baddeley 2007)

The multi-component model of WM first developed by Baddeley and Hitch (1974) and elaborated by Baddeley and colleagues is one of the most empirically validated models of WM. The model conceptualises the multiple components of WM and WM within overarching models of EF, which will be discussed later in the chapter.

Moreover, the model (Figure 7) emphasises separate subsystems of WM as well as executive, attention processes. It describes four separate, but interrelated components: the central executive, the phonological loop, the visuospatial sketchpad, and the episodic buffer, with the shaded area in Figure 8 showing long-term memory systems.

The central executive is considered responsible for the control and regulation of the whole WM system. The phonological loop and the visuospatial sketchpad are two subsystems specialised for storage and processing of material from different information domains. The phonological loop holds information in phonological code and visuospatial sketchpad is specialised for short-term storage and processing of visuospatial information (Baddeley & Hitch, 1974). Later in the model's refinement, the episodic buffer was separated from the central executive and proposed as a multi-domain general system used to synthesise information from sensory modalities and cognitive processes, including WM (Baddeley, 2003; 2007). Baddeley (2007) considered each component of the model would be refined by current research. For example, later research suggests a direct link between the two subsystems and the episodic buffer (Baddeley, 2007), as shown in Figure 7.

Evidence supporting the multi-component model of WM comes from experimental and neuroimaging studies. Experimental evidence comes from dual task studies showing selective interference effects in typical adults. The dual task methodology suggests that if two tasks can be performed simultaneously without considerable drop in performance, these tasks are assumed independent (Mohr & Linden, 2005). Dual task studies have provided evidence for the separation of verbal and visuospatial information domains (Logie, 1986; Baddeley & Hitch, 1974) and the separation of the central executive from passive storage processes (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). Evidence proposes that within the visuospatial domain, a distinction between storage and processing is less clear. For example, studies have suggested there may be a much stronger link between visuospatial short-term memory and the central executive than between the phonological loop and central executive (Miyake, Friedman, Rettinger, Shah & Hegarty, 2001), which is not accounted for by the current multi-component model. Baddeley et al. (*op cit*) suggest that it may be that use of visual imagery is less automatic than the phonological coding of verbal information, hence tasks accessing the visuospatial sketchpad place greater demands on the central executive (Baddeley, Cocchini, Della Sala, Logie & Spinnler, 1999a). Evidence of the episodic buffer comes from studies showing clear links between WM and long-term memory (Baddeley, Vallar & Wilson, 1987) and from studies suggesting association between verbal and visual information (Logie, Della Sala, Wynn & Baddeley, 2000).

Neuroscience studies confirm the component structure of the model and components mapping onto specific brain regions associated with WM (Repovš & Baddeley, 2006). For example, retention of verbal information in the phonological loop activates brain areas in the left hemisphere (Henson, Burgess & Frith, 2000), and visuospatial information activates areas in the right hemisphere (Smith & Jonides, 1997). Tasks that harness the central executive and episodic buffer engage areas of the frontal cortex (Collette & Van der Linden, 2002; Zhang, Zhang, Sun, Li, He & Hu, 2004).

3.3 WORKING MEMORY IN PRIMARY-AGED CHILDREN

From preschool through adolescence WM develops in a linear trajectory (Pickering & Gathercole, 2001), although there are individual differences in WM abilities (Alloway, Gathercole & Pickering, 2006). A study by Davidson et al (2006) of approximately 300 children aged 4-13 years old highlighted important functional and structural changes in neural networks recruited for EFs throughout this age range. WM underlies many aspects of learning and thinking (Dehn, 2011), and holds a central role across a wide range of curricula in addition to numeracy (Ragghubar, Barnes & Hecht, 2010; Swanson & Beebe-Frankenberger, 2004), including literacy (Booth, Boyle & Kelly, 2010; Gathercole & Pickering, 2000b) and science (St Clair-Thompson & Gathercole, 2006). Further, WM is an important predictive indicator of curriculum performance at the ages of 7 years, 11 years and 14 years old (Alloway, Gathercole & Elliott, 2010; St Clair-Thompson et al. 2006). Some evidence states that WM places the greatest constraints on children's numeracy performance (Holzman, Pellegrino & Glaser, 1982), with more specific aspects of WM relating to visuospatial and verbal systems having a critical role in numeracy performance (Bull et al. 2008; Wilson & Swanson, 2001).

In regard to the functional role of WM in children's numeracy development, evidence indicates that WM supports storage of digits, and the retrieval of procedural knowledge (i.e. rules for addition and subtraction, or patterns in multiplication facts), thought to be particularly important for the development of fluency in numerical operations (Krajewski & Schneider, 2009). Nyroos et al. (2011) examined the relationship between WM capacity and numeracy performance using a national curriculum assessment with forty third-grade children. One-way ANOVA, two-tailed

Pearson correlation and multiple regression analyses were conducted. Their findings identified WM as a predictor of overall numeracy performance; albeit different numeracy subareas, as measured by the national curriculum assessment, placed differential demands on the WM system. For example, the study reports WM contributed most to basic numerical competencies, suggesting WM is a domain-general resource, whereas, algorithms, as a domain-specific skill, were not explained significantly by WM. Nyroos et al. (2011) conclude that: (a) the variance of WM was shared across visuospatial and phonological abilities, with both important in numeracy performance, and (b) WM is identified as a key variable in learning and important for consideration by educators.

3.4 WORKING MEMORY AS AN EXECUTIVE FUNCTION

This section considers evidence that situates WM within conceptual frameworks of EF. Some researchers consider WM to be a key EF that helps individuals to regulate and orientate their behaviours across the lifespan (Davidson et al. 2006; Diamond, 2013). Caine and Caine (2006), for example, describe EFs as central mechanisms in the attainment of personal meaning and goals across the lifespan.

Research indicates that development of EFs coincides with the development of regions in the frontal cortex, with different EFs developing at different rates and at different ages (Anderson, 2002; Diamond, 1985, 1990, 2002). Interestingly, Anderson (2002) suggests a growth spurt is likely from birth to 5 years old, although further neuro-imaging and developmental studies are required to draw any conclusions. Besides, developmental stages, the development of EFs is found to be directly affected by a range of ecological factors, particularly poverty (Raver, Blair

& Willoughby, 2013; Rhoades, Greenberg, Lanza & Blair, 2011). Indeed, Diamond (2013) in her seminal paper on EFs cautions that EFs are particularly vulnerable to stress, poor mental health and well-being and sleep deprivation.

An early model of EF was proposed by Anderson (2002) who identified four inter-related EFs as follows: attentional control which is thought to emerge in infancy through early childhood; cognitive flexibility, characterised by WM processes that facilitate switching and generative thinking; goal setting; and information processing with the latter three EFs proposed to emerge between 7 to 9 years old. While Anderson identifies four inter-related domains, the model does not define the parameters of WM particularly well. Further, Anderson does not present evidence to indicate whether different EFs can be separated for measurement, and so has limited practical utility in education contexts, for example. Caution is also required when interpreting the model since tasks used to identify EFs were developed for adults, although used with children. A further general point to consider which relates to Diamond's (2013) cautionary note is the psychosocial context of any participant during the assessment task. EFs are considered active, on-line cognitive and neural processes summoned for specific tasks, which suggests they are likely to be influenced by the participant's environment or contextual factors at the time of testing. Consequently, EFs are likely to be context-specific. It thus follows that to understand task performance or behaviour, researchers are encouraged to explore wider contextual factors and individual performance across multiple tasks (Booth et al. 2010).

A second model of EF is that of Miyake et al. (2000), which breaks important ground demonstrating that EFs are separable, but related. Using latent variable analysis and data from college students on multiple EF tasks, three core and separate EFs were identified: ‘inhibition’ (i.e. being able to regulate our thoughts, behaviours and feelings towards achieving a goal); ‘shifting’ (i.e. being able to selectively focus our attention and mental representations), and ‘updating’ (i.e. being able to respond to or manipulate stimuli as they arise). Lehto, Juujärvi, Kooistra & Pulkkinen’s (2003) subsequent study with Finnish school children across five age groups (8 - 13 years old), confirmed the factor structure of Miyake et al.’s (2000) model to report the same three partially separable, but related EFs independent of age or child IQ. However, a recurrent theme emerging from research studies of EFs is the need for convergence of EF tasks selected, since EF tasks across different studies are often different (Booth et al. 2010).

3.4.1 The multi-domain model of executive function

Diamond’s multi-domain model of EF (2013) is discussed since WM is given central place as the EF underpinning all other EFs; a perspective concurrent with earlier theoretical models of EF (Dawson & Guare, 2009). The model is illustrated in Figure 9 below. Of particular note is the interactionist perspective of the model which posits that the three EFs interact to support each other, but in line with the other theoretical models of EF considered here, identifies these as separable but related (Anderson, 2002; Lehto et al. 2003; Miyake et al. 2000). For example, with reference to Figure 8, being cognitively flexible (or able to actively respond or change perspectives) develops later and builds upon the other two EFs. Thus, to be able to change perspectives one must be able to inhibit any prior perspectives, and activate different perspectives held in the WM system.

Further, the definition of WM proposed in this model is sufficiently comprehensive to accommodate the multi-component structure of WM proposed earlier by Baddeley and colleagues. Additionally, the model is consistent with neuro-imaging studies that indicate the pre-frontal cortex is engaged during EF tasks, albeit that summoning different EFs draws upon other brain regions that are functionally related (Spear, 2013). Neuroscience studies of the brain structures indicate their plasticity, or continuously changing structure and functions throughout the lifespan (Royal Society, 2011). The importance of the brain's plasticity is also considered by Klingberg (2010), and more recently by Diamond (2013) who alludes to evidence that WM is malleable and may be responsive to intervention and training that offers continuous challenge, and which bolster those moderator variables on learning, including motivation (Diamond, 2013; Diamond & Lee, 2011). Therefore, the model has greater practical utility to support interventions for children than the other two major models of EF outlined here.

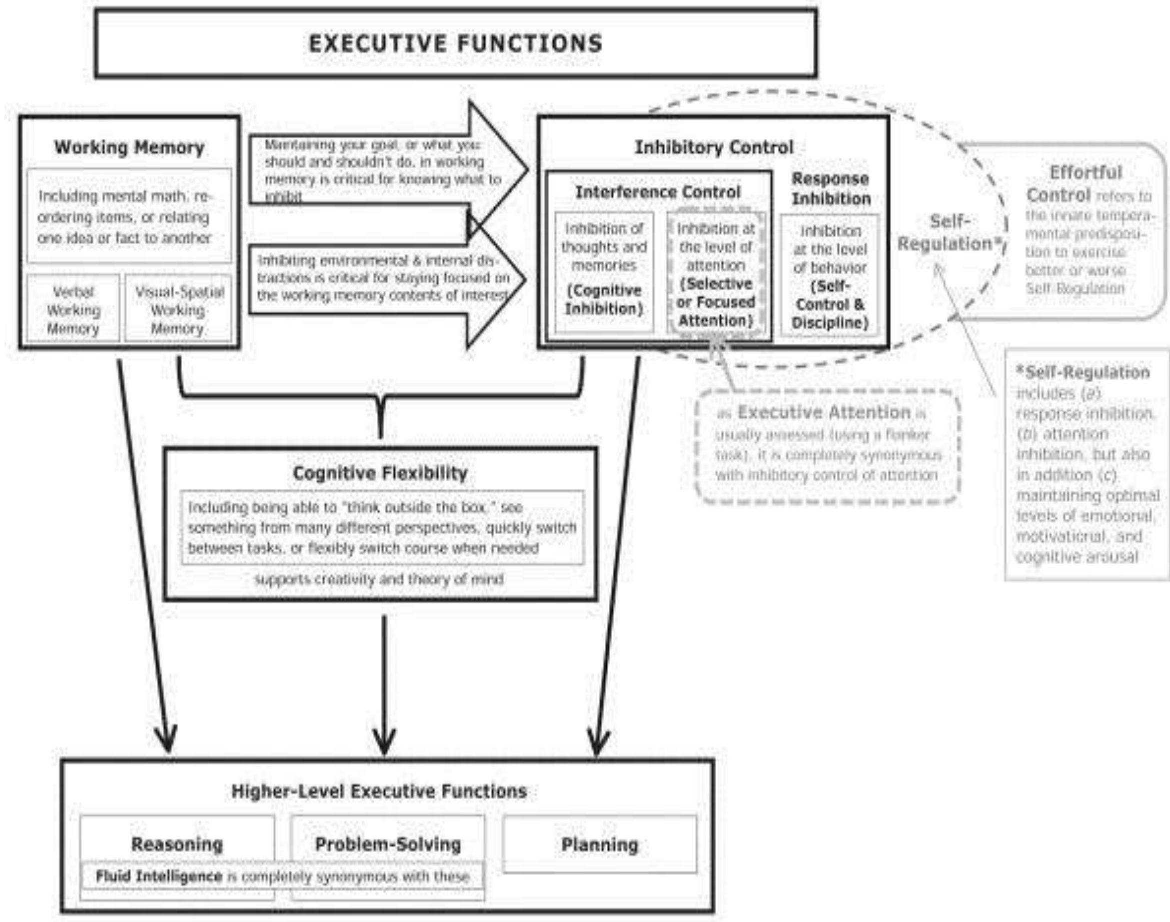

Figure 8: Multi-domain model of executive function (Diamond, 2013, p. 1)

Diamond (2013) proposes that other higher-level processes emerge from the three EFs which are: reasoning, planning and problem-solving, and describes their connection. Making connections between WM and reasoning are not new, and serve to underscore the pivotal role of WM in human functioning (Melby-Lervag et al. 2013). 'Reasoning' or 'fluid reasoning' as it is also termed in the literature was first proposed by Cattell in his theories of intelligence (Cattell, 1987). In general terms, fluid reasoning (FR) is the ability to problem-solve in a logical way in novel contexts across different domains, and is applied when the task requires retrieval of information. Developmental studies indicate FR emerges in the few years of life after motor, attention and other general milestones develop (Cattell, 1987).

The role of FR as a facilitator of WM processes was first elucidated by Cattell and later confirmed by other studies (Demetriou, 2002; McArdle, Hamagami, Meredith & Bradway, 2000). Of particular interest to this study are the correlational studies that propose correlations between FR and WM of .60 to .80 (Kane & Engle, 2002) or .80 to .90 (Kyllonen & Christal, 1990). Such findings were confirmed in an analysis of the literature conducted by Kane, Hambrick and Conway (2005) who reanalysed 14 studies and reported a median correlation of .72, indicating that the two constructs share approximately 50% variance. Correlations have been substantiated by neuroimaging studies that show overlapping brain regions located in the prefrontal cortex engaged during tasks of both WM and FR (Conway, Kane & Engle, 2003; Kane & Engle, 2002), and that both processes develop in similar developmental trajectories across the lifespan (Fry & Hale, 2000). Measurement of FR is most commonly carried out using a matrix reasoning task, which requires the participant to identify the abstract features or patterns between different objects according to a particular association between the objects (i.e. colour, shape, size, orientation). To do so, the participant has to disregard those of no interest, hold relevant information in mind, before selecting the object that matches or completes the identified pattern or relationship. A widely-accepted task of FR is the Matrix Reasoning Task within the Weschler Intelligence Scale for Children or WISC-IV assessment (Weschler, 2004).

However, experimental studies support a reciprocal relationship between WM and FR that makes separating both more problematic in practice (Jaeggi et al. 2010). For example, analysis of the nature of the interaction between WM and FR comes from studies using task completion time as a variable of interest (Jaeggi et al. 2010; Kyllonen & Christal, 1990). These studies control the time provided to complete FR tasks. Results indicate that when the time to complete a FR task is restricted, greater demands are placed on WM to retrieve information at speed, resulting in a greater correlation between WM and FR. In essence, an individual's WM capacity accounts for, or constrains performance on FR tasks (Oberauer, Schulze, Wilhelm & Süß, 2005). Conversely, when time is available to think through possibilities, cognitive processes other than WM are harnessed to solve problems, including, for example, associative learning.

At the time of writing, the *n*-Back task is attracting interest to measure different components of WM and FR. Kirchner (1958) devised the *n*-Back task as a simple method for assessing WM in neuroscience research since the task provides access to a participant's accuracy levels, total scores and response times. With the *2*-back task, the child compares the current trial of the digit string to the trial presented two trials before; thus the child must simultaneously update information with each new stimuli presented and inhibit interference from irrelevant stimuli to then recognise whether the stimuli match or not (Oberauer et al. 2005). For other variants of the task, the child determines whether the last stimulus shown is identical to the stimulus shown '*n*' trials back. With software versions of the task, children press one of two response keys on the keyboard to indicate 'Yes' when the trials match, and 'No' when trials do not match. An illustration of a typical computerised 2-*B*ack task is provided in Figure 9.

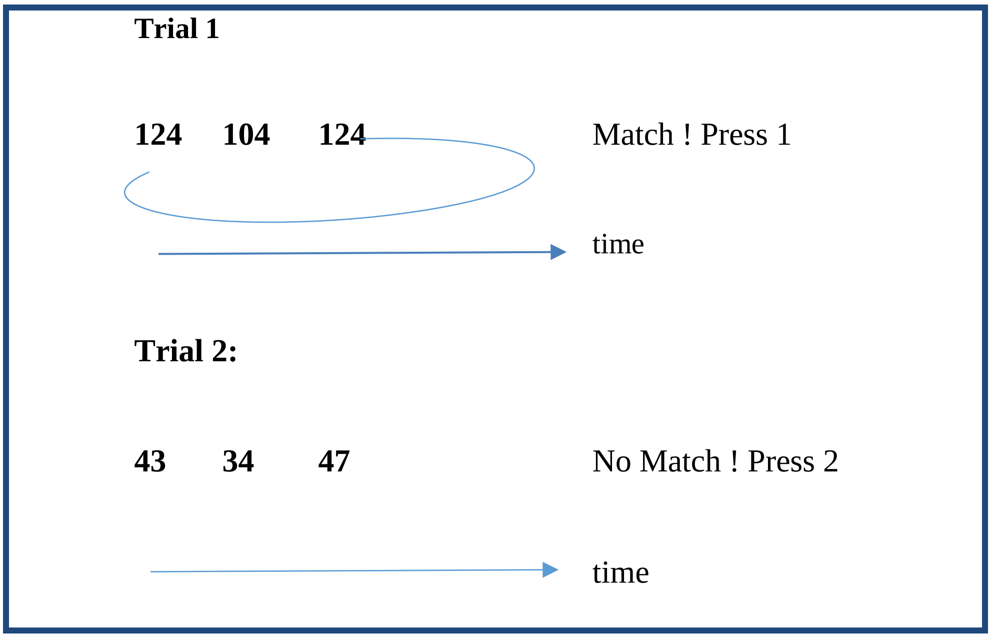

Figure 9: Example of digit trials from the computerised *n*-Back task

However, more recent studies consider the *n*-Back a hybrid task of WM and FR since it may require both inhibition of interfering information, whilst holding salient information in WM (Diamond, 2013; Gray, Chabris & Braver, 2003). The *n*-Back task provides interesting possibilities for exploring the roles of WM and FR when considering Halford, Cowan & Andrews (2007) hypothesis that FR and WM share capacity limitations, and that improvements in WM capacity should result in improvements to FR (Jaeggi, Buschkuehl, Jonides & Perrig, 2008). This hypothesis is the basis for much of the WM and FR training literature which is out with the parameters of this study, but of significance are those studies highlighting FR:

- as a malleable process that responds to training with children aged 7-9 years old (Ferrer, O'Hare & Bunge, 2009)
- as an indicator of numeracy abilities and general academic attainment (Ferrer & McArdle, 2004; Ferrer et al. 2009).

The next section turns to the measurement of WM since reliable and valid measurement directly impacts on monitoring and interventions for children.

3.5 WORKING MEMORY AND EXECUTIVE FUNCTIONS: ISSUES OF MEASUREMENT

Assessment paradigms of EF and WM depend on the theoretical perspectives of the researchers, the research questions and age of participants (Oberauer et al. 2000). This section will first identify some of the challenges facing researchers in the selection of measurement tasks and next outline some methodological issues. Examples of particular measurements of WM and EF are considered to orientate the reader ahead of Chapter 5 which presents an expanded discussion of the rationale for the research design, methodology and instrumentation of this study.

A pertinent issue in the measurement of EFs and WM is task selection and interpretation since as described in the previous section, models of EF have shown their interconnected yet partially separable properties (Diamond, 2013; Miyake et al. 2000). Therefore, Swanson & Siegel (2001) caution that no single task can be taken as a 'pure' measure of any EF. Booth et al.'s (2010) systematic review of the challenges of measuring EF offer recommendations for researchers seeking to minimise 'task impurity' and stipulate: (a) all tasks should be based on theoretical models of EF that clearly define the construct being measured; (b) tasks suit the cultural and developmental needs of the children; (c) multiple tasks are selected to measure the same construct to derive greater reliability and validity for interpretation of the findings since EF share common variance; and (d) where possible, selection of non-verbal tasks minimise the effects of possible language impairments, as language is a mediator in EF development. An additional challenge is being able to interpret findings to actual learning competencies and attainment. An unresolved issue of measurement concerns replacing static, isolated tasks of EF, with tasks that reflect the dynamic deployment of EF in real-world situations (Hughes & Graham, 2002).

Interpretation of measurement should also consider the wider moderator variables on testing performance (Diamond, 2013). For example, motivational factors do influence test performance (Carr & Dweck, 2011). Consequently, Hughes & Graham (2002) recommend the use of a combined mixed methods assessment process, using quantitative methods (i.e. psychometric tasks), alongside qualitative methods (i.e. observation) to allow for reliable and valid interpretations of children's WM and related EF processes.

3.5.1 Measurement of working memory

The most commonly used WM task is the measurement of memory span. Memory span tasks require the individual to accurately process, store and recall maximum amounts of sequential information (Alloway, 2006). These tasks are either 'simple' (those which measure storage) or 'complex' (those which measure storage and processing) (Bayliss, Jarrold, Gunn & Baddeley, 2003). Measurement of word, letter or number span (Daneman & Carpenter, 1980; Gathercole, Willis, Baddeley & Emslie, 1994) all require participants to repeat back sequences of numbers or words of increasing length to provide a measure of verbal short-term memory capacity. Assessment of 'complex' WM uses tasks that combine storage and processing of information for later retrieval (St. Clair Thompson, 2010). A robust and widely-accepted task is the Backward Digit Span task (Weschler, 2004) in which participants listen to a sequence of digits read aloud. They are then asked to respond by repeating the sequence of digits in reverse order, which requires simultaneous storage of the initial sequence of digits and manipulation to process and then recall the digits in reverse sequential order.

3.5.2 Measurement of fluid reasoning

In the previous section the convergent validity or strong correlations between WM and FR were discussed (Owen, McMillan, Laird & Bullmore, 2005). Matrix reasoning tasks are considered in the literature to be one of the most reliable and accepted measures of FR; albeit not the only task (Lohman & Lakin, 2011; Raven, Raven & Court, 1991; Sternberg, 2008), and the Matrix Reasoning task or MR task from the WISC-IV (Weschler, 2004) has been previously described. While tasks of MR require the participant to use visuospatial skills the task itself measures a single factor, reasoning (Weschler, 2004). In line with recommendations aforementioned by Booth et al. (2010) in task selection, matrix reasoning tasks remove language barriers since they are language free and culturally neutral.

However, caution should be noted when selecting MR tasks as they are not considered a comprehensively ‘pure’ measure of FR (Sternberg, 2008). This is unsurprising in light of the research studies discussed in the previous section that demonstrate strong correlations or convergent validity between WM and FR (Owen et al. 2005). Recognising the constraints of MR tasks as a sole measure of FR, Raven (2000) advises researchers to use multiple tasks of FR. With this recommendation in mind, it would be important to measure FR across several sensory domains (Moody, 2009) not just visuospatial awareness, the dominant process in the matrix reasoning task contained within the WISC-IV as described above. A possible way forward is the combined selection of the *n*-Back task as part of a multi-domain approach to measuring FR, since it is recognised by Diamond (2013) amongst others, as a hybrid measure of components of WM (Owen et al. 2005; Verhaeghen & Basak 2005) that converges with FR, including attention and inhibitory control (Conway et al. 2003; Diamond 2013; Jaeggi et al. 2010; Kane et al. 2005). *n*-Back training is well-documented in the literature as a means of developing the malleable processes underpinning FR, albeit at this time the mechanisms underlying the nature of the improvements are less clear and would benefit from further research (Morrison & Chein, 2011).

As a hybrid measurement item (and not a training task), the *n*-Back task has various computerised forms (Owen et al. 2005). Variations on the task relate to how the stimuli are presented, either visual or auditory modalities. The visuospatial *n*-Back is a common variant, where participants are expected to track visual stimuli (i.e. digit strings or shapes) moving across the computer screen (Jaeggi et al. 2008). Other variants are auditory *n*-Back tasks, where participants hear stimuli (such as letters) read to them. If the *n*-Back task involves only one of these modalities, it is known as a single *n*-Back task. A more complex variant, known as the dual *n*-Back task, follows the same concept but requires participants simultaneously track visual and auditory stimuli (Jaeggi et al. 2008). The psychometric properties of the *n*-Back task are discussed in the Chapter 5.

3.6 WHAT HELPS? THE EFFICIENCY AND CAPACITY DEBATE

WM is considered central to learning and thinking as a resource to integrate information from the long-term memory store with information in our temporary store (Dehn, 2011; Swanson & Beebe-Frankenburger, 2004). Thus, poor WM capacity limits the flow of information into the longer-term memory systems and subsequent retrieval for learning. If children are constantly struggling in individual learning situations because they are unable to store and manipulate information in WM, then progress in acquiring complex skills will be slower and more difficult. Indeed, research suggests that learning difficulties are cumulative and enduring with greater decrements in learning as the child matures (Alloway 2008; 2009; Alloway, Gathercole, Kirkwood & Elliott, 2009; Holmes, Gathercole & Dunning, 2009).

By improving children's WM, it is hoped to build capacity for learning to complete complex tasks including reasoning, problem-solving, comprehension and planning (Baddeley, 2007). However, a key issue is whether children with WM difficulties have diminished WM capacity *or* do not make efficient use of WM resources (Alloway, 2009; Dehn, 2011). It is possible to provide support which focuses on the efficiency of WM. This could involve classroom management techniques for reducing WM demands in learning activities; and facilitating the child's use of strategies to prevent WM overload: but such strategies are compensatory in nature and not intended to increase capacity (Alloway, 2011; Gathercole & Pickering, 2000b). If WM capacity is reduced, could it be increased by training, for example through computerised training programmes?

3.7 SUMMARY

Theoretical and empirical studies herald WM as a fundamental process for human cognition since it allows us to simultaneously manipulate and process information as required. This chapter has provided a review of the literature on theoretical perspectives of WM, and has identified Baddeley and colleagues' revised multi-component model as the most helpful to this study since it has been used most widely to understand the contribution of WM to academic attainment. As stated previously, current understanding situates WM within the broader framework of EFs. Diamond's model of EFs (2013) accounts for individual differences by recognising the association of WM with other EF processes, and particular note is made of the strong correlation between WM and fluid reasoning. Further, expanding on WM as an EF, the model acknowledges the dilemmas of measurement, including task selection and impurity. Particular emphasis is made to the model's position on WM as a malleable system that can be improved with continuous challenge and training. Attempts to improve WM capacity in children have normally used computerised training programmes and we shall turn to this in Chapter 4.

CHAPTER 4: COMPUTERISED TRAINING PROGRAMMES AND ATTAINMENT

4.1 INTRODUCTION AND CHAPTER OUTLINE

This chapter explores more recent research studies which aim to improve children's learning outcomes and WM capacity using computerised training programmes. The chapter is in four sections. The first section locates the field of computer-based learning, and the features of serious games within the broader theories of learning and motivation. The evaluation framework of Connolly, Stansfield & Hainey (2009) is selected as a guide to audit potential computerised learning programmes. The second section offers a critique of computerised WM training studies with their claims of near- and far-transfer effects, with particular reference to numeracy performance. Incorporated into this section is discussion of the methodological challenges and limitations of training studies. In the third section, the main computerised WM and numeracy programmes available for children are reviewed and two candidate programmes proposed. Finally, consideration is given to issues of implementation of such programmes in schools.

4.2 COMPUTERISED BASED LEARNING IN EDUCATION

Modern software offers endless possibilities for interactive and experiential learning opportunities (O'Sullivan & Samarawickrema, 2008), particularly for numeracy skills and experiences (Aminifar, 2007; Kulik & Kulik, 1991; Rauscher et al. 2016; Slavin & Lake, 2008). The benefits of computerised games for learning and skill acquisition, with their emphasis on motivation and engagement are widely-recognised in the systematic review literature (Connolly, Boyle, MacArthur, Hainey & Boyle, 2012; Kroesbergen & van Luit, 2003). A feature of computerised games for learning is their emphasis on practical and enjoyable application of skills and knowledge, which is synonymous with the importance of play in children's learning (Vygotsky, 1978) since both computerised games and play provide informal contexts for exploring the world through interaction with the environment which are highly motivating (Bodrova & Leong, 2007; Bruce, 2004). The expansion of experiential and active learning can be operationalised by the experiences and outcomes in the Curriculum for Excellence (Scottish Government, 2004) and Scotland's national Play Strategy (2013).

Increasingly, computer-based or computerised learning is being integrated into the numeracy curriculum, and has gained momentum over the last 15-20 years as this type of learning is cognitive in nature, allowing physical objects, such as blocks used in counting to be represented in 3D on screen (Balacheff & Kaput, 1996). A study by Kucian et al. (2011) explored the possibilities of computerised learning in the development of numerical concepts with children with identified numeracy difficulties (n=16) and children with no observed numeracy difficulties (n=16). Children were aged between 8-10 years. Using a computerised number line programme devised for the study, both conditions completed 5-week computer training, comprising 15 minutes per day, for five days per week. The impact of the training was evaluated by children's performance on neuropsychological tests and functional magnetic resonance imaging (fMRI) during the computerised number line task. Findings were promising for the role of computerised learning in promoting numeracy concepts. For example, children in both conditions improved in tasks of problem-solving and number fluency, suggesting the training programme automatised connections between numerical concepts and procedures. Butterworth

& Laurillard (2010) suggest that positive findings such as these may be accounted for by the spatial virtual environment of computerised learning programmes which present richer opportunities to manipulate connections between concrete and abstract understandings.

4.2.1 Theories of learning and motivation

This study argues that accounts of computerised learning are consistent and best understood within the context of theoretical perspectives on learning and motivation. At a general level, computerised learning offers active, experiential learning with immediate feedback and opportunities for over-learning, all of which are consistent with constructivist theories of learning with learning individualised to learners' needs (Cameron & Dwyer, 2005; Gentile & Gentile, 2008). Further benefits of computerised learning programmes can best be understood within the context of distributed practice and interleaved learning (Pressley, Harris & Marks, 1992) (See Chapter 2 for details). Indeed, evidence from experimental studies suggests that computerised learning is more secure and robust when practice is distributed over a number of sessions, compared to massed practice across fewer lengthier sessions (Fishman, Keller & Atkinson, 1968; Grote, 1995; Wang, Zhou & Shah, 2014).

Accounting for the benefits of distributed practice over massed practice for learning is thought to be more complex than simply concluding that the former allows for practice and consolidation (Cepeda et al. 2006). Distributed practice and the spacing schedule of the items being learned is thought to summon different processing and encoding sequences that activate complex retrieval strategies from the WM system (Schooler & Engstler-Schooler, 1990; Wang et al. 2014). Metalis (1985) analysed the effects of distributed, compared to massed practice on learning the skills required of video gaming. Forty-five participants were randomly assigned to the two respective conditions. The distributed practice condition read a newspaper for two minutes between ten repeated trials of the video game. The massed practice condition played the video trials in ten successive sessions. Participants' learning of the video gaming skills reflected reward points. Findings showed learning opportunities that apply a distributed practice schedule led to both higher performance and greatest improvement in performance scores relative to the massed practice condition.

More recently 'serious games' have emerged as contenders for developing learning and attainment. Serious games combine entertainment with education and learning as the primary driver, using problem-based rules and performance feedback (Zyda, 2005). Zyda (2005) provides a simplistic overview of four key elements in the selection of a serious game which have been adapted and shown in the Figure 10 below:

Figure 10: Elements for the selection of a serious game adapted from Squire and Jenkins (2003) & Zyda (2005).

Zyda (2005) contends that, first the narrative or story of the game is developed to provide entertainment and engagement, supplemented by an attractive, multi-sensory virtual environment. The software including the interface and internet connectivity, are built for user requirements and the pedagogy is considered to ensure activities and games are educational, providing procedural and conceptual learning opportunities. While Zyda (2005) contends that the pedagogy is the final element of game design, Squire and Jenkins (2003) uphold the importance of pedagogical content as integral to narrative development at the initial stages. Therefore, the framework presented in Figure 10 reflects this adjustment.

Moller & Hansen (2016) in a review extracted of the literature identified seven practical details of serious games deemed important for motivation and engagement which could be used in an audit to select a computerised training programme to raise pupil attainment. These details include:

- Simple and quick start to engage participants
- Simple game and instructions (i.e. thematic map)
- Short modules to increase positive outcomes
- Access to learning tools (i.e. instructions, tutorials, clues etc.)
- Feedback and debriefing are integral to the game (i.e. progress bar, level indicator)
- Possibilities for correct errors
- Satisfactory methods to end the game.

Evaluation frameworks are important constructs to audit programmes and can be used to facilitate understandings of pupils' performance and the motivation and engagement strategies which optimise the learning experience (Boyle, Connolly, Hainey & Boyle, 2012). These features are helpful when selecting computerised training programmes, particularly since the market has many programmes, making selection difficult. Connolly et al. (2009) propose a comprehensive and generic evaluation framework (see Figure 11 shown on p.69) selected for use in this study for three reasons. Firstly, the framework is compatible with implementation science principles outlined in Chapter 1. The framework can be used to evaluate the computerised training programme from the perspectives of the individual learner and the 'aide', or adult coach supporting implementation. The framework also allows for implementation science to be incorporated to evaluate the implementation process of computerised training programmes in the school setting. Second, the components of the framework support the empirical evidence about learning and motivation outlined earlier in this section. Thirdly, children's perceptions as learners, and the role of adult as 'aide' for learning are key components of Connolly et al. (2009) framework, which is consistent with the empirical evidence-base of how children learn numeracy and develop in context (See Chapter 2 for details).

4.3 COMPUTERISED WORKING MEMORY TRAINING PROGRAMMES

Computerised WM training is based on the notion of neuroplasticity, or the view that the neural networks in the brain can adapt to systematic, intensive training (Diamond, 2013; Klingberg, 2010; Klingberg et al. 2005). Neuroscience studies confirm that computerised WM training impacts on the structural connectivity within the frontal cortex areas associated with WM and other EFs (Olesen, Westerberg & Klingberg, 2004; Takeuchi et al. 2010).

Most computer training studies have been evaluated using the framework of near- and far-transfer effects (Melby-Lervag et al. 2013; Shipstead et al. 2012). Near-transfer effects refer to those benefits from WM training that transfer to participants' improved performance on similar WM tasks to those trained (Morrison & Chein, 2011). Perhaps more relevant for application to education settings, is the promise of far-transfer effects, which relate to improved performance in tasks dissimilar to those tasks targeted by computerised training programme. Debates can be found in the literature concerning the relative definition of these terms and the merit of quantifying how different two tasks should be to be termed "far" (Conway et al. 2003). For the purposes of this study, far-transfer is understood as transfer between tasks designed and held to theoretically and empirically measure different constructs (i.e. tasks of WM, FR and numeracy are all dissimilar). Near-transfer is understood in this study as transfer between tasks designed and held to theoretically and empirically measure the same underlying processes and / or construct (i.e. measures of WM).

Figure 11: Evaluation framework for computerised training of numeracy and working memory (adapted from Connolly et al. 2009)

EFFECTIVE COMPUTERISED TRAINING

Pupil performance
- Improvements in WM or numerical skills: evidenced from pre- and post-test methodology

Pupil / aide motivation
- Level of interest in participating
- Participation rate over time
- Identified motivators
- What programme features are most interesting?
- Are pupils distracted in any way?
- Motivation of staff to incorporate the programme into class context

Pupil / aide preferences
- Pupil preferred learning modality: with teacher, in groups or with computerised programmes
- Best / worst feature of the computerised training programme
- Instructional preferences for the computerised training programme: isolated task or integral to curriculum

Pupil / aide attitudes
- Pupil attitudes towards WM / numeracy
- Attitudes towards computerised programmes: likeability, sounds, colours, interface, feedback process, usefulness for learning, meeting learning goals
- Attitudes of the Aides towards the programme

Pupil / aide perceptions
- Perceptions of the passing of time within the simulation
- Level of difficulty of the programme
- Self-reported performance / proficiency
- Does the programme help with WM /numeracy?

Collaboration
- Form of computerised training programme – individual, co-operative group, competitive group, multiple groups
- Regularity and level of collaboration: monitoring interactions, or pupil reflections

Computerised training programme environment
- Virtual environment: validation of characters, themes, expressiveness, real-world decision-making
- Scaffolding: clarity of instructions, feedback, quality of support, utility of advice and resources, programme realism
- Usability: average session time, task completion time, error rate, ranking of tasks by pupils
- Level of social presence- immersion in programme, evaluation of character personalities, attitude / mood statements towards programme
- Deployment: most effective way to incorporate programme into context

4.3.1 Can computerised working memory training raise attainment?

Table 3 presents an overview of the research studies which contribute to the currently available evidence-base of computerised WM training programmes. Studies are listed in three sections in line with the format recommended by Harbour & Miller (2001) for grading recommendations in evidence-based guidelines. The first section reports the main meta-analysis studies which are reported on throughout this study. The second section includes quasi-experimental studies, with the focus on selected studies where computerised WM training programmes have been utilised with children and set in education contexts. These studies are critiqued throughout this study. The final section contains those unique few papers reporting expert / informed professional opinion, that have been used by the author to inform understanding about EFs, WM and numeracy and the broader theoretical underpinnings of this study.

Evidence of near- and far-transfer effects comes from quasi-experimental training studies, with the main studies summarised in Table 3. Evidence here demonstrates that computerised WM training can improve WM in typically developing children, children with ADHD, and adults (Holmes et al. 2009; Klingberg et al. 2005; Bergman-Nutley, Söderqvist, Bryde, Thorell, Humphreys & Klingberg, 2011; Thorell, Lindqvist, Nutley, Bohlin & Klingberg, 2009). Later in this chapter, a review of further studies (Bergman-Nutley & Klingberg, 2014; Chacko et al. 2013; Dahlin, 2013; Green et al. 2012; Holmes et al. 2010; Holmes & Gathercole, 2014) is presented in Table 5. These studies are included as they provide evidence for near- and far- transfer effects following training using a particular computerised WM training programme, CogMed (2015). CogMed is reviewed in more detail later.

Important markers for computerised training programmes are made by Melby-Lervag et al. (2013)'s meta-analysis, also summarised in Table 3, which indicate that greatest gains with computerised WM training are made with children under 10 years of age. Next, of all computerised training packages reviewed, adaptive programmes are considered to be the most effective. Adaptive programmes are those where each trial is adapted to the participant's optimal learning or WM capacity and so tailored to their dynamic learning needs (Apter, 2012).

Table 3

Evidence tables for computerised working memory training studies
<u>Meta-analytical studies</u>

Study	Subject/Characteristics of Participants	Design	Summary Outcomes/Comments
Melby-Lervag, M. & Hulme, C. (2013) Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *49*(2), 270-291.	Review of 23 studies, typically developing children & adults. Three age groups included: children younger than 10 years; children aged 11-18 years; young adults younger than 50 years and adults from 51-75 years.	Meta-analytic study reviewing 23 studies with 30 independent group comparisons. Studies included RCT or quasi-experimental pre-post test treated or untreated control groups.	Study indicated that comparing WM training group with control groups, training improved verbal WM (*d*= .79) at immediate post-test measurement, but not sustained at follow-up (d= .31). WM training had some immediate short-term (*d*= .52), and longer-term (at 9 months) (*d*= .41) improvements on visuospatial. Far transfer effects to other measures including non-verbal measures (*d* = .19) & arithmetic (*d*= .07) very small. Interest in domain-specific v domain-general tasks is raised. Limitation - age of sample in this study are merged and use of atypical samples has implications for generalisibility of recommendations. No focus on implementation variables of training studies as a moderator of training transfer effects.
Schwaighofer, M., Fischer, F. & Buhner, M. (2015) Does Working Memory Training Transfer? A Meta-Analysis Including Training Conditions as Moderators. *Educational Psychologist, 50*(2), 138–166.		Meta-analysis study reviewing 47 studies with 65 independent group comparisons.	Meta-analysis identified various implementation variables as moderators of training transfer effects proposed included: duration of training sessions and supervision during sessions. Limitations in line with Melby et al. (2013) i.e. heterogeneity of WM measures used across studies, publication bias (positive gains often published), sample sizes small, thus merged. Effect sizes calculated from gains of difference between training and control groups, which might inflate reported gains, as possible to have improving control group and deteriorating training group. Broad definitions of moderators also used in this met-analysis.

Study	Subject/Characteristics of Participants	Design	Summary Outcomes/Comments
Shipstead, Z., Redick, T.S., Engle, R.W. (2012) Is working memory training effective? *Psychological Bulletin, 138*, 628-654.	Review of: 11 studies with children with low WM / ADHD 5 studies with typically developing children 14 studies with young adults 7 studies with older adults	Meta-analysis study reviewing 37 studies.	Study highlights areas of concern in studies of WM training - methodological issues of task selection and impurity. Claims made by Alloway et al. that WM training improves EF might be overestimated since improvements might represent specific task improvements and not change in underlying ability. Shipstead et al. advocate for removal of non-active control groups from studies given demand characteristics where improvements might be sabotaged due to expectations or Pygmalion effects. Further research & measurement using broader range of WM tasks and far-transfer tasks that are unlike training methods is required when determining direction of transfer between WM training, WM and other EF, and attainment. Limitation – no focus on the implementation variables of training studies as a moderator of training transfer effects.

Quasi-experimental studies

Study	Subject/Characteristics of Participants	Design	Focus of Intervention	Summary Outcomes/Comments
Alloway, T., Bibile, V. & Lau, G. (2013) Computerised working memory training: can it lead to gains in cognitive skills in students? *Computers in Human Behaviour*, *29*, 632-638 Jungle Memory Programme	N = 94 students in mainstream schools with learning difficulties (definition provided)	Quasi-experimental pre-post-intervention design Training frequency = x1p.w. Follow-up period = 8 months Planned variation strategy: Non-active control group: *n*=39, M age = 10.1 Active control group: *n*=32, M age = 10.1 Training group: *n*=23, M age = 11.0	To test near- and far- transfer training effects with computerised WM training programme – Jungle Memory Selected assessment measure: WM = Automated WM Assessment (AWMA). Reliability- verbal WM tests (r = .86) - visuospatial WM tests (r = .84) Ability = verbal ability test (WASI- vocabulary test) - non-verbal ability test (WASI- Matrix test) Academic = spelling & arithmetic tests from WIAT-R	Training group findings - Significant main effects of near-transfer in verbal & visuospatial WM. Significant main effects of far-transfer in verbal & non-verbal skills and spelling Some maintenance effects at 8 months follow-up. Limitations Researcher bias possible- WM programme developed by authors Improvements may represent specific task improvements and not underlying ability Significant differences in performance of training and active control groups relative to non-active control group reported.

Quasi-experimental studies

Study	Subject / Characteristics of Participants	Design	Focus of Intervention	Summary Outcomes / Comments
Thorell, L., Lindqvist, S., Nutley, S.B., Bohlin, G. &Klingberg, T. (2009) Training and transfer effects of executive functions in preschool children. *Developmental Science*, *12*(1), 106-113. Both training programmes developed by authors & CogMed associates.	N = 65 Swedish children Aged 4-5 years old	Quasi-experimental pre-post intervention design Training frequency = 15 mins, 5 days for 25 days Planned variation strategy- Non-active control group- no intervention Active control group- commercial IT games Training groups x2 – WM training or attention training	To test near- and far- transfer training effects to EF with computerised WM training programme using Flankers and Stroop Tasks as assessment measures	Training group findings- near- transfer effects of improved inhibition task performance No far- transfer effects to attention tasks Limitations Researcher bias possible- both programme developed by authors Small effect sizes and non-significant results in the study might be affected by the short periods of training Variations in durations of training were not considered in analysis Unclear whether training effects lasted beyond day of post-testing.

Expert / informed professional opinion

Study	Design	Focus	Summary Outcome/Comments
Anderson, P. (2002) Assessment and development of executive function during childhood. *Child Neuropsychology*, *8*(2), 71-82	Review paper	Mapping development of EF in children – correlations between frontal cortex and EF development Developmental model of EF proposed - 4 inter-related executive domains: attentional control, cognitive flexibility, goal setting and information processing. Developmental pathway: Attentional control emerge in infancy until early childhood. Cognitive flexibility, goal setting & information processing develop between 7-9 years.	Caution needed when using EF tests developed for adults with children Interesting that cognitive processes and behaviour are discordant- both involve different prefrontal cortex systems. More research and neuro imaging studies needed Model proposes only skills that are functional & established are measurable Marginal gender differences for specific tasks noted Useful model as describes interrelated EF processes and clarifies EF components.

Expert / informed professional opinion

Study	**Design**	**Focus of Intervention**	**Summary Outcomes/Comments**
Booth, J., Boyle, J. & Kelly, S. (2010) Do tasks make a difference? Accounting for heterogeneity of performance of children with reading difficulties on tasks of executive function: findings from a meta-analysis. *British Journal of Developmental Psychology*, *28*, 133-176.	Meta-analysis of 48 studies Children included in the study aged below 16 years Range - 9.5-11.5 years.	Meta-analysis carried out to clarify predicting variables of effect sizes i.e. age, gender and IQ on tasks of EF. Review considered whether IQ/attainment discrepancy definitions of reading difficulty (RD) had been used and whether EF tasks required verbal / non-verbal responses	Findings Across 48 studies, selection criteria for EF tasks varied considerably. Role of IQ in RD is unclear, since tasks of IQ include verbal and non-verbal tasks making role of either in RD unclear. Gender was found not to influence effect sizes. Limitations - Selection of EF tasks with established levels of construct validity i.e. based on theoretical models of EF & suit developmental & cultural needs of children. Task impurity issues identified Where possible, EF measures should use non-verbal tasks to circumvent any language impairments which shown to be mediator in EF development. Age not identified as variable in EF task performance. However, limited age range across 48 studies (between 9.5-11.5 years).
Butterworth, B. (2005) The development of arithmetical abilities. *Journal of Child Psychology and Psychiatry*, *46*(1), 3-18.	Review paper	Review of evidence on how arithmetical abilities develop & variables of interest	Article provides a developmental overview of how arithmetic skills develop across early childhood. Numerosity develops from counting in words and then one-to-one correspondence. Subitising is next stage and then conservation of numbers / set. Review suggests there is causal link between EF and arithmetic
Diamond, A. (2013) Executive Functions. *Annual Review of Psychology*, *64*, 135-168.	Review paper	Comprehensive critique and overview of EF development across life span Multi-domain model of EF	Evaluative stance on many measures of EF. Inhibitory control being EF where further research could establish measures with greater validity and less task impurity. Separability of EFs -importance of interplay between different EFs helps to identify compensatory skills. Attractive model - outlines EF processes; relates them to intelligence & greater utility for intervention Identifies further research to est. why some children benefit from EF training and some do not, and what factors impinge upon on sustainable gains.

However, far-transfer effects have been more difficult to substantiate. The rationale for computerised WM programmes is that WM is a malleable (Diamond, 2013; Kilngberg, 2010), domain-general attention resource that underpins other complex tasks. Therefore, it follows that training-transfer effects should be present in complex domains (i.e. far-transfer) such as numeracy, not just scores on WM tasks (De Smedt et al. 2009a; Geary et al. 2004; Holmes et al. 2009; Thorell et al. 2009). Indeed, a number of studies claim that computerised WM programmes effectively develop WM capacity which transfers to improvements in attainment in key curriculum areas (Alloway et al. 2013; Chacko et al. 2013; Melby-Lervag et al. 2013; Shipstead et al. 2012; Titz & Karbach, 2014). If this interpretation is correct, WM training should result in both *near-transfer* effects (tasks similar to those trained) and also *far-transfer* effects (tasks different to those trained). This hypothesis is of theoretical and practical importance to this study as it means any impact should generalise, to observable positive changes across different aspects of children's learning.

Promising evidence from developmental research has indicated evidence of far-transfer effects to other different EFs in children including, attention or 'on task' behaviour in the classroom (Green et al. 2012; Thorell et al. 2009), inhibitory control (Kilngberg et al. 2005) and fluid reasoning in children with ADHD (Jaeggi et al. 2008). However, recent meta-analysis studies (Bushkuehl & Jaeggi, 2010; Melby-Lervåg et al. 2012; Shipstead et al. 2012) reveal a lack of evidence for far-transfer effects. Shipstead et al (2012) and Melby-Lervag et al. (2013) observe that stronger evidence is required to demonstrate far-transfer effects, that is, to broader areas of learning, such as numeracy attainment, or domain-specific tasks.

The remainder of this chapter provides a critique of the computerised WM training studies to date, to consider methodological challenges in the field.

4.3.2 Methodological issues from computerised working memory training studies

Methodological constraints in the training studies are highlighted by Shipstead et al (2012) and Melby-Lervag et al. (2013), and more recently by Schwaighofer, Fischer & Buhner (2015). These are summarised in Table 4 below.

Table 4

Overview of methodological issues and implementation variables from meta-analytical working memory training studies (Melby-Lervag et al. 2013; Schwaighofer et al. 2015; Shipstead et al. 2012).

Methodological issues identified from WM meta-analysis studies	
Sample characteristics	Small sample sizes
	Heterogeneous sample
Suitable control groups	Non-active control group
	Active control group
Task selection	Heterogeneous tasks
Task administration	Testing fatigue
Computerised WM training programme properties	Bespoke programmes
	Adaptive v non-adaptive
Implementation variables identified from WM meta-analysis studies	
Programme implementation	Fidelity
	Dosage
	Quality
	Differentiation
	Reach
	Adaptations

Melby-Lervag et al. (2013) indicate that many of the studies of computerised WM training programmes have been carried out with small sample sizes which makes generalisation of findings for future replication studies problematic. However, caution should also be noted when interpreting meta-analytic studies. In Melby-Lervag et al.'s (2013) meta-analysis, effect sizes of heterogeneous samples were grouped and ranged in age, with participants ranging from typically developing children, children with low WM capacity, children with ADHD and specific learning difficulties. The assortment of different tasks used to measure WM and the difficulties interpreting findings that provide valid information for future replication studies (see the earlier section of this chapter on task selection issues) have been highlighted in meta-analysis studies outlined in Table 3, and independent expert opinion (Booth et al. 2010). Perhaps future meta-analyses could consider specific subgroups to allow conclusions about any training-transfer effects on specific populations.

Further methodological challenges which impact on the validity of the studies have also been noted in the literature. A fundamental limitation of many study designs that measure or train WM is that they have not included a suitable control condition (Melby-Lervag et al. 2013; Schwaighofer et al. 2015). Frequently, studies use only non-active control groups, whereby participants receive no treatment relative to a training condition. Unfortunately, this means that any differences reported between treatment conditions and non-active control condition may be explained by participants' expectancy or Hawthorne effects, rather than the properties of the training task (Sternberg, 2008). In other words, a participant's performance may improve simply as a result of receiving attention from the experimenter (McCarney et al. 2007). Hence, both non-active and active control conditions are selected in this study design in attempt to minimise the Hawthorne effect, or the impact of motivational influences on test performance (Carr & Dweck, 2011), and any other threats to validity emerging in research designs (Cook & Campbell, 1979).

Diamond (2013) notes that for WM training to be effective, tasks should continuously challenge the WM system. Incremental challenge is important, not just to ensure that participants engage, but also for participants' active agency to drive improvement. When tasks are too easy and comfortable, participants make less effort to master them (Ericsson, Nandagopal & Roring, 2009). Researchers have identified that an optimum level of challenge in training tasks allows differences between conditions to emerge (Davis et al. 2011, Diamond, Barnett, Thomas & Munro, 2007). Therefore, researchers are advised to select adaptive training programmes since they have the greatest impact to improve WM capacity (Dunning, Holmes & Gathercole, 2013).

A final issue arising in the literature is the range of programmes used across studies (Schwaighofer et al. 2015). Some studies used bespoke programmes that were developed by the researchers themselves, which introduces researcher bias (Robson, 2011). The next section now turns to consider in more detail the main computerised training programmes reported in the literature and included in Table 3 and 5.

4.3.3 What computerised working memory training programmes are available for primary-aged school children?

Two main computerised WM training programmes found in the literature include: CogMed © (2015) and Jungle Memory © (Alloway et al. 2013). A third, Memory Quest Flex Junior © (Truedsson & Strohmayer, 2010) is considered by the author as it is available within the local authority the study takes place. First, CogMed (2015) WM training or CWMT (www.cogmed.com) is widely used as it has substantial research demonstrating improvements in WM capacity and far-transfer effects to other attainment outcomes (Chacko et al. 2014; Dunning et al. 2013; Holmes & Gathercole, 2014; Klingberg et al. 2005), including numeracy (Dahlin, 2013) and is the focus of Table 5. CWMT is a 5-week training programme designed for daily use in school or at home over 25 training days in total. Each training session takes approximately 30-45 minutes to complete. Only licensed centres or certified coaches can use CWMT, which greatly limits its availability in schools. However, none of the studies where CWMT was reviewed report on the use of a qualified coach in the implementation of the programme (Chacko et al. 2013; Green et al. 2012; Holmes et al. 2010).

CWMT purports to increase WM capacity rather than train WM strategies through training and coaching of storage and processing of verbal and visuospatial WM components in line with the revised multi-component model of WM discussed in Chapter 3. CWMT is available for three developmental stages: preschool children, school-aged children and adults, and can be used with learners struggling with WM tasks and children with Attention Deficit Hyperactivity Disorder (ADHD). The programme has an attractive user interface, with game-like features, and robot characters provide reinforcement and brief reward games. Table 5 below, shows a summary of the effect sizes reported by some of the CWMT studies with children. Evidence and claims by CWMT are available in a summary report (see http://www.cogmed.com/wp-content/uploads/CogmedClaimsEvidence.pdf for further details.

Table 5

Summary of studies where CogMed programme yielded significant training effects

Study	Transfer effects	Selected measures	Effect Size: Cohen's *d* or η_p^2
Bergman Nutley & Klingberg (2014) Randomised treatment conditions	Near-transfer to WM tasks Far-transfer to numeracy attainment	Bespoke measures adapted from the Automated WM Assessment (AWMA) 'Odd One Out' task 'Following Instructions' task Numeracy task developed by CogMed Publishing	 *d* = .60 *d* = .69 *d* = .44
Chacko et al. (2013) Randomised treatment conditions	Far-transfer to educational attainment & reduced symptoms of ADHD	Digit recall task Spatial recall task Dot matrix task Listening recall task	*d* = .28 *d* = .29 *d* = 1.70 *d* = .07
Dahlin (2013)	Far-transfer to numeracy attainment for children with learning difficulties and ADHD	Basic Numeracy Screening Test (Gillham et al. 2013) Digit Span Backwards (WISC-III) Visuospatial Backwards Span Board Raven's Matrices	*d* = .69 *d* = .79 *d* = .92 *d* = .50
Green et al. (2012) Randomised treatment conditions	Far-transfer to 'on task' classroom behaviour for children with ADHD	WM composite score from the Working Memory Index in the WISC-IV (Weschler, 2004) (incl. digit span and letter-number sequencing	*d* = 1.31
Holmes et al. (2009)	No far-transfer effects to reading or maths At 6-month follow-up the training group showed significant gains in maths reasoning	Automated WM Assessment (AWMA) Verbal STM Visuospatial SMT Verbal WM Visuospatial WM Control Group Verbal STM Verbal WM	 *d* = .62 *d* = 1.20 *d* = 1.55 *d* = 1.03 *d* = .49 *d* = .48
Holmes et al. (2010) Non-randomised single treatment condition	Near-transfer in single condition design	Automated Working Memory Assessment (AWMA) (Alloway, 2007) WASI (Weschler, 1999) Verbal WM Visuospatial WM	 η_p^2= .29 η_p^2= .15
Holmes & Gathercole (2014)	Near-transfer to WM tasks Far-transfer to numeracy	National Standard Assessment Test (SAT) in numeracy AWMA Backward Digit Recall Counting Recall Visuospatial WM Mr. X Spatial Recall	*d* = 1.15 *d* = 1.34 *d* = .05 *d* = .78 *d* = .98

Interpreting Cohen's *d* or effect sizes – Small (.2), Medium (.5), Large (.8)

Interpreting Cohen's η_p^2effect sizes – Small (.02), Medium (.13), Large (.26). (Cohen, 1988)

Critical analysis of the methodological and reporting issues of several of the CWMT studies suggests that the reported improvements in children's WM and symptoms of ADHD following the training should be read with some caution. For example, Green et al. (2012) reported significant improvements in trained WM tasks relative to the control group, although the small sample size prevents identification of group performance differences and limits generalisability. Next, Chacko et al. (2014) in a randomised clinical trial of 85 children aged 7-11 years with ADHD, reported significant developments in WM storage, but not storage and processing combined, and no far-transfer effects to other domain-specific tasks were found. In conclusion, Chacko et al. (2014) claim CogMed is not a viable intervention to support children with ADHD to access the school curriculum.

Studies of CWMT also indicate inconsistencies across training paradigms. Chacko et al. (2014) highlight a lack of equivalence between treatment and control groups, while Holmes et al. (2010) used only a one treatment group design. Further, although similar levels of compliance are reported in both studies; the time spent on task, the nature of the coaching and implementation variables have not been matched across studies (Chacko et al. 2013; 2014; Holmes et al. 2010). For example, Chacko et al. (2013) administered CWMT sessions lasting around 40 minutes a day, for around 25 days in children's homes. Conversely, Holmes et al. (2010) administered 20-25 sessions over a 6-10-week intervention phase in children's home. Green et al. (2012) administered ninety tasks from CWMT in school over 24 days. While the programme offers valuable continuous web-based data management facilities to monitor participant progress, the cost may be prohibitive to local authorities in these straitened times, particularly for use at the whole school level. The annual license costs £480 for 2 adults and 20 users (CogMed, 2015).

The second programme reported in the training literature is Jungle Memory (Alloway et al. 2013) which is a web-based subscription programme purporting to train WM in children aged between 6-16 years old. The programme is adaptive, offering 20 levels of games. Games are based on visuospatial sequencing of words, patterning and mental arithmetic, with tasks tapping WM and short-term memory components. Children are encouraged to play the game at least four sessions per week for approximately 20 minutes per session. Evidence of the efficacy of Jungle Memory is a single published study conducted by the programme designer, which deserves caution in light of possible researcher bias (Robson, 2011). However, upon closer examination, the methodology and reported results raise significant questions, which are outlined in Table 3, and discussed in previous sections.

The Jungle Memory programme (www.junglememory.com) costs approximately £35 for a single 8-week subscription, meaning it is available on a single laptop computer, which prohibits its use as a whole class / universal intervention in this study. The programme may be considered a hybrid programme since it incorporates short-term memory, WM and numeracy tasks. Indeed, hybrid programmes are recommended by Gathercole (2014) to generate transfer effects that are functional with practical benefits. However, for the purposes of this study, a systematic computerised WM training programme based on the revised multi-component model of WM selected (Chapter 3) is required for a whole class of children, thus testing the hypothesis of whether the domain of the computerised training privileges WM (domain-general) or numeracy (domain-specific) performance.

4.3.3.1 Memory Quest Flex (Junior)

Memory Quest Flex (Junior) (www.memoryquest.com) is the third WM training programme considered. It is an online, adaptive software programme designed to train and improve WM capacity of school-aged children (Truedsson & Strohmayer, 2010). Typically developing children can use the programme and it is also accessible to children with a range of difficulties, including poor WM, ADHD, or other learning difficulties. Memory Quest is available via a CD-ROM, and the Memory Quest Flex alternative software is accessed on-line. There is a Junior version suitable for primary-school aged pupils and a Senior version suitable for secondary-aged pupils. The programme was developed by a multi-agency team comprising educationalists, psychologists, software developers, musicians and illustrators. There are ten adaptive modules with eight different exercises in each module. Exercises link very well to the revised multi-component model of WM since they require the child to both store, manipulate and process stimuli in visuospatial and verbal modalities. Memory Quest Flex (Junior) minimises the need for language since instructions are given verbally at a pre-reading and writing level, but are also demonstrated visually at the start of each exercise. The software has a diverse reward and motivational system with an embedded narrative to engage children over the duration of the training schedule. A manual provides advice to staff or the coach on the preparation, implementation and evaluation of the programme using a training schedule. Children are encouraged to maintain a log book to track and monitor progress. The programme manual advises five sessions for five weeks of approximately 30-50 minutes per session. The cost of an annual site license for under 150 users is £185.

Memory Quest Flex Junior (Truedsson & Strohmayer, 2010) is under-researched in comparison to the other two programmes described, and merits further research and evaluation with typically developing children. Truedsson & Strohmayer (2010) carried out small research studies with children with ADHD and report positive results. Nevertheless, the research was conducted by the authors themselves, provides no information on validity and has not been published other than to report positive findings shared in the manual accompanying the software. The programme is selected as the candidate computerised WM training programme for this study for four reasons. First, it incorporates verbal, visuospatial WM tasks and central executive attentional tasks in line with the revised multi-component model of WM (Baddeley, 2003; 2007); second, the authority in which the study takes place has already invested and its effectiveness has not yet been determined, and it can be evaluated at no additional cost; third, the tasks are of sufficient complexity to maximise transfer of training effects (Diamond, 2013). Finally, analysis of the programme indicates that it adheres to those key elements of computerised training programmes generated by Connolly et al.'s (2009) evaluation framework (Figure 11).

4.3.4 What computerised numeracy training programmes are available for primary-aged school children?

Computerised numeracy training is appropriate for this study as numeracy is best operationalised using contextual situations rather than abstract and written calculations (Carraher et al. 1985). Formal and abstract instruction which does not connect with pupils' learning experiences has been found to hamper numeracy attainment (Meiers et al. 2006; Westwood, 2008). Rather, we have seen from Table 2 which outlines evidence-informed principles of effective numeracy approaches which include, multi-sensory learning experiences that are exploratory and investigative, which use a range of games-like principles to maximise numeracy attainment (McInerney, 2013; Moyer & Jones, 2004) and retrieval of numeracy facts (Ozdemir, Guneysu & Tekkaya, 2006). There are several computerised numeracy programmes available, but the main programmes found included: Number Quest Flex © (Truedsson & Strohmayer, 2010); Mathletics © (www.ukmathletics.com); Destination Success Maths © (Riverdeep Interactive Learning, 1995); The Number Race © (Wilson & Dehaene, 2004); Dybuster Calcularis © (https://dybuster.ch/en/calcularis) (Kucian et al. 2011) and Study Ladder © (Study Ladder Holdings Ltd, 2013). License costs prohibited the use of both Number Quest Flex and mathletics.com in this study. At the time of writing Destination Success Maths had been discontinued by the providers and was no longer available.

The Number Race Version 2.0 (www.thenumberrace.com) (Wilson & Dehaene, 2004) is an adaptive computer training programme aimed to support children aged between 5-8 years with dyscalculia i.e. a core learning deficit in number sense and linking numbers to their symbolic representations (Dehaene, 2011). Wilson, Dehaene, Pinel, Revkin, Cohen & Cohen, (2006) also suggest the programme can be used with typically developing pre-school children. The programme is devised from the theoretical underpinnings of dyscalculia with games designed to train children's recognition of and fluency with numbers and quantities through comparisons of number sets, digits and number words up to forty, and addition and subtraction problems within ten. The game focuses on developing the child's mental number line by reinforcing the three counting formats i.e. digit, sets and hearing the number words. The adaptive feature places additional demands upon the participant to select within a time scale, or to compete against a competitor avatar (Wilson et al. 2006). The programme is free to download.

There are four published evaluation studies of The Number Race at the time of writing. In the earliest study, Wilson, Revkin, Cohen, Cohen & Dehaene's (2006) evaluated the programme with French school children aged 7-9 years (*N*=9) who participated in 5-week training, four days per week, with each session lasting approximately 30 minutes. Children were selected from three primary schools based on class teacher recommendation informed by the children's long-standing difficulties with numeracy. Results suggest significant improvements in core number sense tasks for accuracy and fluency when comparing digits and counting sets. Further, accuracy and fluency of subtraction with simple numbers within 10 improved. However, benefits did not generalise to counting or arithmetic. While these early results from use of The Number Race are promising, it is important to note that the sample was not randomly selected from a large population of children with numeracy difficulties and no control condition was included in this study, making generalisation of findings problematic.

In a later study, Wilson, Dehaene, Dubois & Fayol (2009) evaluated The Number Race with a larger sample of French kindergarten children (*N*=53) from two indicated provisions in areas of low socio-economic status. A two-period cross-over design with a control group accessing a commercially available computerised reading programme was used to compare training effects. Significant results are reported and maintenance effects at 6-week follow-up were observed. For example, children's accuracy when making comparisons between representation of digits and dots improved, yet when only non-symbolic number tasks were presented, performance did not improve. These results suggest The Number Race programme may develop the links children make between symbolic and non-symbolic representation of number rather than their number sense per se. These results are inconsistent with the benefits reported in the previous study (Wilson et al. 2006) and may partially be explained by the low socio-economic status of the sample. It is possible that children from lower socio-economic backgrounds are less exposed to symbolic and non-symbolic representations of number in the home learning environment.

In a later study by Rasanen, Saminen, Wilson, Aunio & Dehaene (2009) The Number Race programme was compared to another training programme, Graphogame, which similarly aims to train children's number sense through comparisons of number sets, digits and number words with simple addition and subtraction problems. Finnish children aged 3-4 years old, with indicated numeracy difficulties were randomly allocated to the two intervention conditions, receiving training in either The Number Race (*n*=15) or the Graphogame (*n*=15). Both groups received brief daily training (approximately 15 minutes) over a 3-week training phase. A control condition (*n*=30) with no identified numeracy difficulties was used as a comparison group, albeit Rasanen et al (2009) reflect that there were large differences between the three groups at baseline. Both training conditions yielded moderate significant intervention effects (average effect size of .44) with reported improvements in children’s arithmetic and comparison of numbers relative to the control condition of typically developing children. However, no improvements were reported for other areas tested, which included verbal counting or object counting. It is important to note that the training period in this study was extremely brief and repetitive, with a typical training session of approximately 15 minutes. Results may indicate practice effects. Further, interpretation of the results is problematic due to several confounding variables that do not control for the Hawthorne Effect. For example, the comparison in this study was between two programmes of similar content. To control for the Hawthorne Effect future replication studies could use a programme with similar activities but different content, and a control group receiving only their regular kindergarten curriculum with a similar cohort of children to those in the intervention conditions i.e. children experiencing numeracy difficulties.

Drawing conclusive recommendations about the use of The Number Race with primary school-aged pupils for this study is problematic. The emerging evidence-base for the programme arises from its use with pre-school children with numeracy difficulties, and at the time of writing no studies were available of its efficacy with typically developing primary school-aged pupils. Consequently, the focus of measurement in the above studies is more limited than the aims of this study, which are to detect developments in numeracy attainment. While the programme can be downloaded at no additional cost, gaining permission to download software onto school network computers from the Information Technology Service within the local authority this study takes place involved a lengthy procedure that would be out with the timescales of this study.

Dybuster Calcularis or Calcularis as it is oftentimes referred (Kucian et al. 2011), is an adaptive online computerised training programme designed to help children to formulate and access a mental number line by training number fluency. The programme offers training in arithmetic across large number ranges and covers the four operations including addition, subtraction, multiplication and division. Children answer an array of number problems that are represented using dots, digits or as written algorithms, by placing responses on a number line using a joystick. Rauscher et al. (2016) evaluated Calcularis in a study design incorporating two different approaches with a large sample (*N*=138). Children aged 7-10:11 years were randomly allocated to three conditions including: a Calcularis training group (*n*=43), an untrained waiting control group (*n*=49) and a computerised spelling training group (*n*=46). In the first study approach the Calcularis condition was compared to the untrained waiting control group to control for developmental or schooling effects. In the second approach, the Calcularis condition was compared to the computerised spelling condition to control for Hawthorne Effects and explore the nature of any training effects. Both training conditions trained at home, 5 times per week with daily sessions of 20 minutes for 6-8 weeks.

Results indicated that the Calcularis training condition reported moderate to large effect sizes relative to the control group on measures of subtraction and number processing using the number line for lower number ranges (numbers 0-10). Relative to the computerised spelling training group, results indicated small effect sizes on the same measures. No gains were identified in children's addition skills for the Calcularis group, and limited improvements were noted in number processing using the number line for higher number ranges (numbers 0-100). The latter finding may suggest that had children received longer training sessions their access to the number line for higher number ranges may have improved.

These results are encouraging, although basic numerical skills, including comparisons of number and quantity and subitising skills were not included in the assessment batteries for this study. These are key numerical skills required of the daily curriculum in primary schools, and so the ecological validity of the results make drawing recommendations for the use of Calcularis in this study problematic. Further, an audit of Calcularis by the author using the framework of Connolly et al. (2009) to guide the selection of effective games-based learning programmes highlighted that Calcularis does not meet key components of the framework. For example, Calcularis does not have an embedded narrative and a limited reward system of certificates and earning coins to spend in virtual shops. Finally, the cost of an annual site license for 50 users is approximately £582, which prohibits its use in the local authority this study takes place.

4.3.4.1 Study Ladder

A comprehensive and adaptive online computerised training programme, Study Ladder © (Study Ladder Holdings Ltd, 2013), is available in schools in the authority where this study takes place, yet it had not been readily taken up and there were no known published studies or local authority research on its use with school children. The programme merits further study since it purports to transform children's numeracy attainment through interactive and adaptive web-based learning environments. Children have concrete supports in the form of physical manipulatives to explore and apply numeracy concepts tailored to their individual level of challenge. Language demands are also minimised with instructions given verbally and visually demonstrated at the start of each exercise. Study Ladder uses problem-based models of instruction (Savery, 2006; Savin-Baden, 2007) that maximise attainment through individualised learning pathways, progress monitoring and feedback. A learning management system is also available.

Study Ladder is under-researched, and with no known published studies on its effectiveness, it merits further research and evaluation. The programme is selected as the candidate numeracy training programme for a further two reasons. Second, the programme provides exercises that cover the four operations of number using multi-sensory approaches concurrent with staged and cognitive models of numeracy development (Chapter 2). More specifically, researchers identify these approaches to numeracy as important to support children translate connections between concrete and abstract numeracy concepts and improve numeracy performance (Burns, Codding, Boice & Lukito, 2010; Wadlington & Wadlington, 2008). Finally, analysis of the programme suggests it adheres to those aspects outlined by Connolly et al. (2009) of efficacious computerised learning programmes.

4.4 IMPLEMENTATION CHALLENGES WITH COMPUTERISED TRAINING PROGRAMMES IN SCHOOLS

At the time of writing, components of implementation of computerised training programmes in schools are under-researched. A fundamental constraint for computerised training programmes in schools holds that technology remains problematic to embed in the daily curriculum due to teachers' perceived lack of training and their sense of ownership over the technology (Cordova, Eaton & Taylor, 2011; Guzman & Nussbaum, 2009). Other issues in the literature indicate teachers' low perceptions of their technology skills to use software effectively, which may leave them feeling deskilled and reluctant to use technology at all. This may present real challenges for researchers seeking to introduce software to schools, and further barriers to efforts seeking sustainability of technology in classrooms (Holden & Rada, 2011).

However, opportunities afforded by computerised training programmes are also noted in school contexts. Computerised training programmes can often be carried out in quiet settings with small groups of pupils. Both variables are important mediators for effective learning since general movement and noise found in classrooms can create unfavourable listening conditions putting unnecessary strain on WM capacity to store, decode or manipulate stimuli, leaving limited capacity to process information (Klatte, Hellbrück, Seidel & Leistner, 2010). Further, small group learning opportunities maximise engagement and numeracy attainment (Anthony & Walshaw, 2009) since small groupings afford learners opportunities to practice and consolidate procedural and conceptual knowledge (Vaughan, Moody & Schumm, 1998), and provide the space to use and apply dialogue, important in the development of reasoning and logic (Hunter, Gambell & Randhawa, 2005; Sfard & Kieran, 2001; Williams, 2008).

4.5 SUMMARY

Computerised training programmes offer promise for optimal learning and transfer of learning to different contexts since their designs are informed by theoretical perspectives of learning, feedback and motivation (Boyle, Terras, Ramsay & Boyle, 2013). The selection of two candidate computerised training programmes was guided by the evaluation framework of Connolly et al. (2009) since it supports those perspectives of learning and allows for evaluation of the implementation variables using understandings from implementation science (Durlak & DuPre, 2008).

This chapter outlined the benefits of computerised WM training under research conditions which have been the subject of recent systematic reviews and meta-analyses. Table 3 and Table 5 evidence the near-training transfer effects to measures of WM. Particular note was made of the inconclusive evidence for far-transfer effects (Shipstead et al. 2012), compounded by methodological limitations across studies that included: researcher bias, small sample sizes; inappropriate control groups, and other diverse implementation issues (Alloway et al. 2013; Schwaighofer et al. 2015) which merit control in future studies.

Findings from training studies using the main computerised WM training programme, CogMed © (2015) are discussed, but the cost of CogMed is prohibitive for use by the local authority where the study took place. Instead, Memory Quest Flex (Junior) (Truedsson & Strohmayer, 2010) is selected as the computerised WM training programme and Study Ladder (Study Ladder Holdings Ltd, 2013) as the computerised numeracy training programme for this study. Chapter 5 now turns to the rationale for the study research design and instrumentation.

CHAPTER 5: METHODOLOGY

5.1 INTRODUCTION AND CHAPTER OUTLINE

The five purposes of this chapter are to (1) present the rationale for the research design of this study, (2) explain the sample selection and randomisation procedure, (3) describe the instrumentation process, (4) provide an explanation of data collection and audit of implementation, and (5) outline the rationale for data analysis.

5.2 PURPOSE OF THE STUDY

The literature reviewed in the first four chapters of this thesis highlighted the importance of numeracy for lifelong learning and outlined the convergence of theoretical frameworks to understand numeracy development (Bryant, 1995; Butterworth, 2005; Dehaene, 1997; Bull et al. 2001). As we have seen, key learning approaches to develop numeracy attainment in schools reflect multi-sensory pedagogical approaches and the use of computerised learning to maximise experiential learning opportunities across the widest possible contexts (Askew et al. 1997). Of particular interest here, is the unique shared variance between numeracy and WM (estimates range from 35-45%) (Raghubar et al. 2010), with improvements in WM associated with improvements in numeracy performance (Adam & Hitch, 1997; Alloway & Passolunghi, 2011; Bull et al. 2001; Fuchs et al. 2006; McLean & Hitch, 1999; Passolunghi & Siegel, 2001).

The revised multi-component model of WM (Baddeley; 2001; 2003; 2007) offers a framework with which to separate the WM components that account for unique variance in numeracy performance and attainment. Diamond's model (2013) of executive functions embeds these WM components within a broader neural network of executive functions, with strong correlations between WM and FR noted. Further, Diamond's model offers a practical framework for understanding individual differences in children's WM and attainment, hence offers hope that WM is malleable to improvement through rigorous and continuous challenge. Adaptive computerised WM training programmes that offer continuous challenge report success to improve WM capacity (Melby-Lervag et al. 2013), and also offer promise as vehicles for understanding transfer of learning to different contexts (Gathercole, 2014).

Systematic reviews indicate that while WM training programmes may yield 'near-transfer' effects resulting in improved scores on measures of WM, there is less convincing evidence for 'far transfer' effects generalising to academic skills in areas such as numeracy (Melby-Lervag et al. 2013; Shipstead et al. 2012). Those studies reporting far-transfer effects should be read with caution given the methodological dilemmas when measuring WM and the varied research design of these studies, especially in their limited consideration of control groups (Schwaighofer et al. 2015).

Before turning to the research questions, it is important to summarise the evidence base detailed in Chapters 1 - 4, which underpin the research questions of this study:

(i) Working memory is malleable and can be improved with practice (Diamond, 2013; Klingberg et al. 2005)

(ii) Working memory is linked to educational attainment (Gathercole et al. 2004)

(iii) Working memory is measurable, and the tasks and instruments used are reliable and valid to do so (Daneman & Carpenter, 1980; Diamond, 2013; Unsworth, Weschler, 2004)

(iv) The population sample is representative of the general school-aged population

(v) Participants have not participated in previous computerised training programmes, thus ensuring no contamination between conditions through application of their prior knowledge, to circumvent possible ceiling effects

(vi) Participants can use a personal computer.

5.3 RESEARCH QUESTIONS

The following research questions will be addressed in this thesis:

1. Does the computerised WM training improve scores on standardised measures of WM within a primary 3 age-group, identified as a key stage by Davidson et al. (2006, p.41) on account of functional and structural changes in neural networks? (i.e. near-transfer effects)
2. Does the WM training transfer to fluid reasoning and numeracy tasks? (i.e. far-transfer effects)
3. Does the computerised numeracy training programme improve scores on standardised measures of numeracy within a primary 3 age-group? (i.e. near-transfer effects)
4. Does the computerised numeracy training programme transfer to improve scores on standardised measures of WM (i.e. far-transfer effects)
5. Following Anderson (2002), does gender have an effect upon the outcome?

6. Do perceptions of numeracy have an effect upon the outcome?
7. How acceptable or feasible is the use of computerised WM and numeracy training programmes in mainstream primary schools in the Scottish context?

With the purpose and aims of this study outlined, matters of research design are considered first to inform the design of this study.

5.4 RATIONALE FOR RESEARCH DESIGN

This section details the rationale for the research design and selection of suitable methodology to answer the research questions and develop interpretations. Research methodology has to be robust to minimise errors that arise from data collection and analysis (Boyle & Kelly, 2017). Validity and reliability are key research issues at the heart of quality research designs and outcomes (Cook & Campbell, 1979; Weir, 2005), and so are discussed in this chapter. Next, the benefits of the randomised control trial or RCT, and a critique of its use in educational settings is outlined. As an alternative, quasi-experimental designs are considered, and the inherent compromises with validity and reliability are grappled with (Torgerson & Torgerson, 2008), before outlining the research design selected for this study.

5.4.1 Validity and reliability

Validity and reliability are the common terms used to designate accuracy and consistency in the selection of measurements, interventions and judgements about research outcomes. Validity, according to Ukrainetz & Blomquist (2002, p. 60) describes:

how well a test measures what it is purported to measure.

This definition implies that validity is all important, not only in the selection of valid assessment measures but also for the inferences, or sense made of assessment outcomes. As Messick (1989, p. 6) describes, validity:

always refers to the degree to which empirical evidences and theoretical rationales support the adequacy and appropriateness of interpretations and actions based on score meaning.

Cook and Campbell (1979) identify four types of validity relevant to research design: internal validity, external validity, construct validity and statistical conclusion validity. An expanded overview of the first three types of validity is presented in the following section. Statistical conclusion validity is considered towards the end of this chapter. Taking internal validity first, it denotes the degree to which the relationship between two variables indicates causality. For example, if different researchers analysed the findings of a particular study and all identified similar conclusions, the study would be considered internally valid. Cook & Campbell (1979) identify 12 threats to internal validity pertinent to this study, which are summarised in Table 6 below. The table includes reflections on how the research design of this study might explicate or minimise these threats.

Table 6

Summary of 12 threats to internal validity (Cook & Campbell, 1979, p.50-55)

Threats to internal validity	**Description**	**Steps taken in this study design plan to explicate or minimise threats**
History	Occurrence of an event between pre- and post-intervention	• Implementation audit
Maturation	Change within participants between pre- and post-intervention	• Unlikely given brief duration of study • Sample from targeted age group (7-8 years old) • Pre- and post-Pupil's Perceptions of Numeracy Questionnaire • Implementation audit
Testing	Number of times participants' responses are measured	• Simple pre- and post-assessment design minimises testing trials • Parallel forms used for numeracy test • Selection of planned, statistical analyses that control error rate arising from multiple pairwise comparisons
Instrumentation	Changes in measurement instrument between pre- and post-intervention	• The same measurement instruments were administered at pre- and post-intervention • Baseline statistical checks established equivalence of groups • Implementation audit
Statistical regression	Observed score shift between pre- and post-intervention may arise from measurement error when participants are classified into intervention groups	• Sample size calculated from statistical power analysis • Matching of schools to minimise group non-equivalence prior to randomisation to condition • Pupils assigned to intervention groups independent of pre-test score performances • Selection of pre- and post-test measurements with strong test-retest reliability co-efficient values • Baseline statistical checks to establish group equivalence • Inter-scorer reliability checks
Selection	Differences between participants in the different intervention groups	• Matching of schools to minimise group non-equivalence prior to randomisation to condition • Participants selected by age • Baseline statistical checks to establish group equivalence

Threats to internal validity	Description	Steps taken in this study design to explicate or minimise threats
Mortality	Changes in the sample by the post-intervention stage	• Missing data analysis • Implementation audit
Ambiguity about the direction of causal influence	Unclear how variables of interest influence each other	• Pre- and post- assessment design • Selection of active and non-active control groups to explore direction and nature of any training-transfer effects • Implementation audit
Diffusion or imitation of interventions	Planned differences are reduced by communication between intervention groups	• Randomisation at class level with school as nested factor
Compensatory equalisation of treatments	Planned differences between intervention groups are reduced by compensatory measures to reduce or reverse differences between groups	• Selection of intervention group, active and non-active control groups for comparison • Randomisation at class level with school as nested factor • Implementation audit
Compensatory rivalry by participants receiving less desirable intervention	Participants are motivated to reduce or reverse expected differences between intervention groups	• Non-active control group reassured access to most successful intervention after study • Pupils' Perceptions of Numeracy Questionnaire (PPNQ) • Implementation audit
Resentful demoralisation of participants receiving less desirable intervention	Participants underperform when receiving less desirable interventions, or the control group	• Non-active control group reassured access to most successful intervention after the study • Implementation audit

Next, Cook & Campbell (1979) described external validity, as one of the most difficult types of validity to achieve in research design. For Cook & Campbell *(op cit)* external validity refers to the extent to which inferences from research studies can be generalised across populations or subpopulations, across settings or time-points. The authors argue that with real-world research design, random sampling for representativeness is rare since variations exist across and within the experimental groupings. Therefore, differentiated findings cannot be generalised to the population, but can be generalised across the specified subpopulations in question.

Cook & Campbell (1979) outline three main threats to external validity (p.70-80) pertinent to this research study which are summarised in Table 7 below. How these threats might be explicated or minimised in this study are considered.

Table 7

Summary of three threats to external validity (Cook & Campbell, 1979, p.70-80)

Threats to external validity	**Description**	**Steps taken in this study design plan to explicate or minimise threats**
Interaction of selection and treatment	Systematic recruitment factors introduce bias since findings are only applicable to the participants	• Deliberate purposive sampling in one local authority locality with an identified target group of primary school-aged pupils • Access was not granted for opportunistic sampling • Randomisation to conditions at class level with school as nested factor • Participants elect to participate and can withdraw at any stage of the study • Verbal consent is obtained from participants at outset
Interaction of setting and treatment	Selection and characteristics of the setting or groups can introduce volunteer bias and make causal inferences problematic since those settings or groups selected are often open to the change process	• Clear research questions identifying the scope of the study with Primary 3 school-aged pupils • Schools matched on numerous variables before selection • Randomisation to condition at class level with school as nested factor • Varied conditions that include: treatment, active and non-active control conditions
Interaction of history and treatment	Causal inferences may be affected by historical effects	• Literature review using graded recommendations in evidence-based guidelines that included: quasi-experimental studies, systematic reviews, meta-analyses and expert / informed professional opinion, to identify prior evidence of causal inferences from computerised training programmes • Follow-up period derived from the literature review, to determine any maintenance effects • Implementation audit

The third type of validity is construct validity which is considered the most important, underpinning all other forms of validity in research design (Cook & Campbell, 1979). Construct validity refers to the quality and degree of the causal relationship between variables, and holds that when these variables are linked together by statistical and theoretical networks, the research findings can be generalised across the wider population and other settings (Cook & Campbell, 1979; Cronbach & Meehl, 1955; McMillan & Schumacher, 2006).

Cook & Campbell (1979) outline nine main threats to construct validity in research design (p.59-68) which are summarised in Table 8 below. How these threats might be explicated or minimised in this study are considered.

Table 8

Summary of nine threats to construct validity (Cook & Campbell, 1979, p.59-68)

Threats to construct validity	**Description**	**Steps taken in this study design plan to explicate or minimise threats**
Inadequate pre-operational explication of constructs	Construct being researched or measured is inadequately defined	• Clear definitions of all dependent variables informed by research literature
Mono-operational bias	Only a single operationalisation of a construct, making triangulation difficult	• Multiple tests selected to measure each construct • Selected tests have strong test-retest reliability coefficient values • Implementation audit
Mono-method bias	Response bias or acquiescence when a single method of representation of a construct is presented	• Multi-domain testing: verbal, paper-and-pencil and visual modalities accessed using electronic presentation of *n*-Back task using E-Prime software
Hypothesis-guessing within intervention groups	Participants guess the research aims	• Information and consent letters carefully worded to remove any bias towards intervention type • Random class allocation to conditions, including the use of active and non-active control conditions • Implementation audit

Threats to construct validity	**Description**	**Steps taken in this study design plan to explicate or minimise threats**
Evaluation apprehension	Participants being apprehensive about being evaluated by researchers	• Implementation audit
Levels of the construct, or intervention, become confounding constructs	Different manipulations or levels of the construct, or intervention, which are not differentiated in measurement	• Each intervention group receive a different adaptive computerised training programmes • Selection of a non-active control group to explore impact of any near- and far training transfer effects
Interactions of different treatments	Participants receive more than one intervention, making it difficult to separate the effects of one intervention over another received	• Randomisation at class level with school as nested factor design
Interaction of testing and intervention	Participants are tested multiple times which may condition their response to the intervention	• Simple pre- and post- testing phases reduced participant exposure to testing • Parallel forms used in numeracy test • Selection of tests with strong test retest reliability coefficient values • Follow-up period in place to determine any maintenance effects.
Restricted generalisability across constructs	Limited number of constructs are measured leaving the total impact of the intervention on a range of other constructs unknown	• Selection of a non-active control group to explore impact of any near- and far training transfer effects • Near- and far-transfer effects measured using multiple measures • Implementation audit

The focus now turns to reliability in research design, which is concerned with the repeatability, or dependability of measurement (Robson, 2011). Two main types of reliability of relevance to research design are typically reported in the literature. First, temporal consistency, which refers to the reliability of research findings over time (Cook & Campbell, 1979; Muijs, 2004). Second, internal consistency, or the consistency with which individual items of measurement either correlate with each other, or the total score on the item of measurement, which is held to show that the items of measurement are in fact measuring the same construct (Robson, 2011). Internal consistency is frequently measured using the Cronbach alpha coefficient, with scores ranging from .00-1.00; with values at or above .75 indicating adequate internal consistency reliability (Field, 2013).

Another form of bias worthy of note is response bias, which poses a common threat to validity and reliability. Response bias refers to observed findings that participants' responses on a measure are consistently higher or lower than the actual population score (Robson, 2011). Since this study will seek to determine the feasibility and acceptability of interventions, two types of bias most relevant are non-response bias, and social desirability bias. A research design may contribute to non-response bias when participants have a choice of whether or not to respond, or when participants refuse to respond. Either response is problematic, since it is likely that responses from those opting out would be different to those who agreed to take part, making reliability of responses difficult to establish (Robson, 2011).

Social desirability bias refers to distorted responses influenced by what participants perceive the researcher expects, or may be influenced by participant drive to portray themselves in a favourable stance (Robson, 2011). Czaja & Blair (2005) describe that social desirability bias is more prevalent when participants are requested to respond to emotional or sensitive constructs. However, this may be minimised by reassuring participants of anonymity and confidentiality.

5.4.2 Randomised control trial research designs

In experimental research, the Scottish Intercollegiate Guidelines Network (2015) proposes a hierarchy of evidence determined by weightings given to the robustness of a study's internal validity, or the degree to which outcomes provide causal evidence that the intervention is effective for change. The Scottish Intercollegiate Guidelines Network (*op cit*) considers the randomised control trial or RCT, the 'gold standard' in experimental research design. In RCT the unit of randomisation is the individual participant, which balances any confounding variables between conditions, thus controlling any sources of bias associated with measurement error and test reliability. Sampling from the population is random and so the selected groups are considered equivalent groups, providing high levels of internal validity, with findings that can be generalised to the wider population, making external validity robust (Cook & Campbell, 1979; Robson, 2011). In essence, RCT rule out many of the threats to reliability and those threats to validity summarised in Tables 6 - 8 above.

Making reference to Boyle & Kelly's (2017, p.35) typology of evidence table, adapted from Petticrew & Roberts (2003), RCT are typically utilised to answer higher-order research questions of intervention effectiveness, safety and cost of interventions, and whether users would be willing to take up the intervention in the future. Torgerson & Torgerson (2008) identify seven elements of RCTs:

1) participants receive an appropriate intervention
2) sufficiently large sample size
3) participants are assigned to a condition and a comparison or control group
4) random allocation to the conditions

5) pre- and post-intervention measures are identified in advance to measure outcomes
6) follow-up measures are in place to determine maintenance of any changes
7) significant differences between conditions provides causal evidence that the intervention is effective for change.

5.4.3 Critiques of randomised control trials

Interventions found to yield positive outcomes in RCT designs are worthy of cautionary note for real-world researchers. For example, RCT are underpinned by positivist theory, which holds that there is one truth, or absolute understanding of the world (Kelly & Perkins, 2012; Robson, 2011). Indeed, RCT were originally designed for use in the medical sciences, where significant control over variables of interest to be included, and those to be ruled out is possible in laboratory settings. Consequently, Evans (2003) suggests the RCT holds minimal relevance for policy-makers and educationalists. Further, researchers suggest that when attempts have been made to apply interventions found to be effect from RCTs to educational context, outcomes have been variable (Dane & Schneider, 1998; Durlak & DuPre, 2008).

Implications of the common unit of randomisation in RCT are worthy of further discussion. Most RCT randomise at the level of the individual participant (Field, 2013; Torgerson & Torgerson, 2008). However, the feasibility of randomisation at the individual pupil level in educational settings presents significant challenges in practice and resourcing. For example, pupils are already grouped by class in education and there is often a limited number of classes in any one school, thus it is practically not possible to randomise individual pupils at class level to different intervention conditions, or groups.

A secondary dilemma of ownership emerges for the author should pupils be randomised at the individual level. As a practising EP, the author aims to encourage school ownership of this research study, to ensure that the study meets the needs of those participating schools and builds staff capacity to implement the intervention in their unique settings. There is a risk that the interventions would not be taken-up by schools to the same extent if randomisation is at the individual level (i.e. as the RCT recommends), since each condition in the design would comprise pupils from a range of schools.

Constraints in the process of randomisation arose from the Educational Psychology Service in which the author was employed as an educational psychologist. The sampling frame would comprise only those schools the author worked as the link educational psychologist. Another consideration for this study design is to minimise diffusion of interventions. Therefore, each class could be selected from a different school, with ‘school’ as a nested factor in the design (Torgerson & Torgerson, 2013). However, this would mean there would be non-equivalence between class groups, since it is expected there will be differences in different classes in different schools. An appropriate step to minimise non-equivalence between schools, would be to match schools on a range of key variables prior to random assignment to intervention groups (Robson, 2011; Torgerson & Torgerson, 2008).

5.4.4 Quasi-experimental research designs

Quasi-experimental designs identify reality as objective and constructed by individuals, and where rarely, there is one 'truth' (Robson, 2011). Quasi-experimental designs may combine the use of mixed methodologies to identify and understand the ecology and social processes that underpin real world settings (Boyle & Kelly, 2017; Cook & Campbell, 1979). Mixed methods consist of quantitative data methods selected to determine the outcome of interventions, and which are triangulated with qualitative methods, such as focus groups or questionnaires (Robson, 2011), to understand more fully the process of the intervention; its acceptability and feasibility to participants and wider policy makers (Kelly & Perkins, 2012). Again, referring to Boyle & Kelly's (2017, p.35) typology of evidence table, adapted from Petticrew & Roberts (2003)'s for use by educational psychologists in practice, quasi-experimental designs are utilised to answer research questions concerned with whether an intervention is effective, safe and acceptable to users.

Torgerson & Torgerson (2008) identify two elements of caution when researchers consider quasi-experimental designs:

1) Non-random allocation of participants to groups brings threats to validity particularly non-equivalent groups, selection bias and regression to the mean
2) Potential for pre- and post- intervention measures to be compared in the absence of a control group

In planning the research design of this study, it was important to consider how a robust quasi-experimental design may minimise those two threats. Taking the first point, as stated previously, individual randomisation of pupils in this study is not desirable for encouraging school ownership, and is not practically possible. However, cluster randomisation at class level is possible, with ‘school’ as a nested factor design. With this understanding, the expected differences in different schools are explicated at the pre-design stage of the research. A proposed attempt to balance the equivalence of the school groups and minimise selection bias, is to match schools by demographic characteristics before selection. Further, those matched schools could then be randomly allocated to intervention groups using random number tables to minimise selection bias and regression to the mean (Torgerson & Torgerson, 2008).

Now considering the second threat to validity and reliability; pre- and post-intervention measures could be identified in advance, and a post-intervention follow-up timescale identified from the literature to detect any maintenance effects. Next, a quasi-experimental design would be more robust with a control group. A control group, where participants receive no intervention, would allow comparisons between pre- and post- intervention measures with the group receiving the primary intervention, which for this study, is the computerised WM training, and a non-active control group, receiving only the regular curriculum. Yet, a more robust design still, would be to include an active control group, where participants receive an alternative or competing intervention (Boyle & Kelly, 2017) as a planned variation strategy (Rivlin & Timpane, 1975). In this study, the active control group could receive the computerised numeracy training programme, selected as a more robust design method to compare any impact of near- and far- training transfer effects of computerised training and to make observations about the acceptability and feasibility of computerised training programmes in the setting of Scottish mainstream primary schools.

However, Cook & Campbell (1979) also suggest caution when making inferences from statistical analyses, as threats to statistical conclusion validity include:

- random irrelevances in the research setting (unrelated to the intervention)
- reliability of implementation of the intervention
- random heterogeneity of participants

These threats to validity arise from the study context and are especially pertinent to this study, since it aims to answer questions directly related to the acceptability and feasibility of the computerised training programmes for both pupils and teachers in educational settings.

The next section turns to consider possible ways this study design might explicate and minimise threats to validity that arise from the educational settings and the implementation of the interventions themselves.

5.4.5 Implementation audit

Implementation science, as discussed more fully in Chapter 1, emerged in response to a growing need to promote positive changes in real-world contexts by triangulating or cross-validating quantitative outcomes with the complex social processes that underpin these settings (Gottfredson & Gottfredson, 2002). Dane & Schneider (1998) in a meta-analysis study investigated programme integrity and adherence of implementation across 231 studies, and concluded that that these two elements compromised internal validity in many of the studies reviewed. The stance of this study then is to harness the value-added and practical utility of quasi-experimental designs that combine qualitative methods into the quantitative frame of reference (Evans, 2003).

To minimise those threats to validity arising from the study setting (Cook & Campbell, 1979), checks on validity are proposed by an implementation audit. Indeed, the application of an implementation audit in this study is advised, but often missing from efficacy studies of computerised training programmes (Schwaighofer et al. 2015). The implementation audit would comprise:

- implementation checklist
- staff coaching
- staff training schedule
- staff impact questionnaire
- pupil log book
- pupil focus group

The selection of these implementation tools was informed by the conclusions drawn from those studies included in Table 3 in Chapter 4, and from the implementation science literature (Fixsen et al. 2005; Kelly & Perkins, 2012; Kelly, Woolfson & Boyle, 2017). Further details about the implementation audit are presented later in this chapter.

5.5 SUMMARY REMARKS ON RATIONALE

To summarise, this study offers a robust research design combining implementation science within a quasi-experimental design to explicate and minimise threats to reliability and validity. Specific steps taken include:

- sample size indicated for minimal levels of significance
- randomise assignment to groups at class level, with schools matched in a nested factor design
- use of intervention, and both non-active and active control groups
- pre- and post-intervention measures identified in advance from the research literature
- follow-up measures used within acceptable timescales, indicated by the literature, to determine maintenance of any change
- audit of the implementation of the intervention across groups, using a range of measures

The reader is also referred to Tables 6 and 7 for details on the research design attempts to minimise the threats to validity inherent in quasi-experimental designs.

5.6 STUDY RESEARCH DESIGN

This thesis consists of three studies, with the third study divided into two parts. To orientate the reader by way of overview of the studies, Table 9 is presented below.

Table 9

Summary of data sources, types and analysis procedures applied by research question

Study	Research Question	Data source	Data type	Data analysis procedure
1	1-5	Standardised test measures: WM; FR; Numeracy Computerised *n*-Back task: Response time & total score	Interval Interval	• Change score analysis • Meta-analysis
2	6	Pupil Questionnaire	Nominal	• Principal Component Analysis
3 Part 1	7	Pupil focus groups	Qualitative	• Thematic analysis
3 Part 2		Staff training schedule Staff impact questionnaire		

5.6.1 Participants

This study took place in the second largest local authority and the fifth most populated in Scotland. The local authority has high levels of deprivation with 5.5% of the population living in the most severely deprived data zones.

5.6.2 Randomisation procedure

The author only had access to those primary schools within the locality in which she worked as the link educational psychologist. The demographics of those schools were matched prior to possible selection to minimise selection bias, in terms of their similarity in geography, denominational status, school roll and Scottish Index of Multiple Deprivation (SIMD) (Scottish Government, 2012). SIMD is considered a more comprehensive predictor of deprivation than free school meals, which all children up to Primary 3 in Scotland are entitled (McKinney, Hall, Lowden, McClung & Cameron, 2012). From the literature, school pupils aged 7-8 years old would be invited to participant in this study since this age is identified in the literature as a key stage for the development of EF and WM (Anderson, 2002; Davidson et al. 2006; Diamond, 2013). Therefore, the Primary 3 class was the indicated sample. Interestingly, Anderson (2002) also reported marginal gender differences in children's EF tasks. Gender effects are not routinely reported in studies in this area, but in light of Anderson's (2002) findings, might warrant further investigation.

The earlier section provided details about the selection and randomisation procedure, with three classes from three different primary schools randomly allocated to each of the three conditions using random number tables using a computational random numbers generator to minimise any allocation mishaps or subversion (Torgerson & Torgerson, 2008). Table 10 provides a summary of key variables used to match the primary schools.

Table 10

Variables used to match primary schools for selection in the study

Demographic Indicators	School 1: WM computerised training *Memory Quest Flex Junior*	School 2: Numeracy computerised training *Study Ladder- Maths*	School 3: Control Typical curriculum instruction only
School type	Denominational mainstream primary school		
School roll	274	279	282
SIMD	41.8% severe deprivation	40.2% severe deprivation	39.2% severe deprivation
HMIe Inspection & Awarded Achievement Scale	10/2007 'Good'	01/2009 'Good'	10/2006 'Good'

In this study, all the Primary 3 pupils in the three matched schools participated in the appropriate intervention. Making reference to Chapter 1, the underlying premise of the study is to offer a universal intervention, so it would not be feasible, or ethical to eliminate some Primary 3 pupils from the study. Inclusive selection of the full population of Primary 3 pupils increases the heterogeneity of the sample across the three schools; improving the generalisability of findings across similar target sub-populations in the local authority (Cook & Campbell, 1979; Nesbary, 1999; Patten, 2004).

Seventy-six primary school pupils (mean age = 89 months, *SD* = 3.47) participated in the study (see Table 11). They were English native speakers, with seven children having English as an Additional Language (EAL) whose first language was Polish and who had attended the school for over one year. One Polish child dropped out of the study to return to Poland. Children with EAL were evenly distributed across the three schools. Sample size was calculated from the minimal score difference which could be detected by the least reliable of the standardised instruments used as primary outcome measures (Boyle et al. 2007; Boyle & Kelly, 2017). Using a one-tailed test at 5% level of significance and a power of .80, a total sample size of 72 pupils was required. This equates to a Cohen's *d* Standardised Effect Size (Field, 2013) of .74. Studies, reviewed and included in the evidence tables in Chapter 3, indicate that standardised effect sizes of 1.10 to 1.20 might be expected following computerised training in a sample of similar aged participants (Holmes et al. 2009; Thorell et al. 2009). Calculation of Cohen's *d* confirms that the anticipated effect size is feasible and that the planned sample size is adequate.

Table 11

Characteristics of the sample of participants

	Computerised WM training condition	Computerised numeracy training condition	Control Condition	Total Sample
Sample *n*	25	27	24	76
Pre -Age months M (SD)	89.0 (3.47)	90.1 (3.77)	89.7 (3.88)	89.6 (3.69)
Post- Age months M (SD)	93.0 (3.47)	94.1 (3.7)	93.7 (3.88)	93.6 (3.69)
n (female)	25 (12)	27 (14)	24 (11)	76 (37)
n (E.A.L)	3	2	2	7

Gender balance and sensitivity were considered, and would have been sought using stratified random sampling to achieve 50% gender balance in each sample of pupils from each school class to take part in the study (Robson, 2011). However, this process was not required as the gender balance criteria of 50% was naturally found in the two intervention conditions. However, in the Control condition, 50% gender balance was not possible given there were 11 females in the class of 24 pupils.

The next section of this chapter outlines the (a) design, (b) instrumentation, (c) rationale for data collection and, (d) rationale for data analysis for each of the three studies in turn. The following three chapters then present the procedure and results of each study.

STUDY 1: EVALUATION OF TWO COMPUTERISED TRAINING PROGRAMMES

5.7 RATIONALE AND AIMS

To evaluate two computerised training programmes to develop WM and numeracy in primary school-aged pupils.

5.7.1 DESIGN

A quasi-experimental between-subjects repeated measures factorial design was used to compare the effects upon primary school-aged children aged between 7-8 years in three mainstream primary schools in Scotland of a 7-week computerised WM training program *Memory Quest Flex (Junior)* (Truedsson & Strohmayer, 2010) (*n*=25) with a 7-week computerised numeracy training programme, Study Ladder (2013) (*n*=27), both relative to a non-active control condition receiving only their regular curriculum (*n*=24). The independent and dependent variables of the study are shown in Table 12 below:

Table 12

Summary of the independent and dependent variables for Study 1

Dependent variables **(Variables being measured)**	**Independent Variables**
Performance scores on measures of Working Memory (WM) • Backwards Digit Span task (abbreviated to Digit Span Backwards -DSB) (Weschler, 2004)	**Time point** • Pre-intervention stage (T1) • Post-intervention stage (T2)
Performance scores on measures of Fluid Reasoning (FR) • Matrix Reasoning task (MR) (Weschler, 2004) • *n*-Back (2-back) task- Total Score (TS) and Response Time (RT) (Schneider, Eschmann & Zuccolotto, 2012)	**Condition** • Computerised WM (Condition 1) (Truedsson & Strohmayer, 2010) • Computerised Numeracy (Condition 2) (Study Ladder Holdings Ltd, 2013) • Non-active control (Condition 3)
Standardised score on numeracy test • Basic Numeracy Screening Test (Gillham, Hesse & McCarty, 2012)	**Gender**
Perceptions of numeracy • Ratings on Pupils' Perceptions of Numeracy Questionnaire	

5.7.2 Ethics

This study was carried out in accordance with the British Psychological Society's Code of Ethics and Conduct (BPS, 2009) and Code of Human Research Ethics (2010) and the Health Care and Professions Council's Standards of Conduct, Performance and Ethics (SCPE) (HCPC, 2016). Ethical approval for this study was granted by local authority's Educational Psychology Service and the University of Strathclyde School of Health and Social Sciences Ethics Committee.

All data gathered was anonymised and stored securely so that no participant could be identified. The secure storage of all data complied with the ethical research standards indicated above and the Data Protection Act (1998).

5.7.3 Consent

Parents/carers of participating children (who were aged between 7-8 years) were asked to complete a consent form from the University of Strathclyde which also provided information about the study (Appendix B). Children's whose parents/carers agreed to participation were also briefed by the author and provided their own verbal consent, recorded by the author (Appendix C). All participants were informed that they could withdraw from the study at any time. No participants withdrew from the study.

5.8 INSTRUMENTATION

5.8.1 Software

Memory Quest Flex (Junior) (Truedsson & Strohmayer, 2010) was selected as the computerised WM training programme for this study. Study Ladder (Study Ladder Holdings Ltd, 2013) was selected as the computerised numeracy training programme for this study. Details of the programmes and rationale for their selection are provided in Chapter 4.

None of the participating schools had used either programme previously which ensured sources of historical bias were minimised since no pupils were using prior learning which could contaminate results (Cook & Campbell, 1979).

5.8.2 Measures

Primary outcomes are the outcomes selected to answer the research questions of the study and are informed by the literature (Higgins & Green, 2012). Primary outcome measures form the basis of the statistical power of this study and have been used to calculate the sample size, as described in the earlier section. Secondary outcome measures are additional variables of interest which do not hold central value to the research questions. Rather, they may be used to support interpretation and triangulation of findings from the primary outcome measures, thus providing further information for future research (Higgins & Green, 2012).

5.8.2.1 Rationale and selection of primary outcome measures of working memory

The primary outcome measure of WM comprised a subtest selected from the *Wechsler Intelligence Scale for Children* (WISC-IV) (Wechsler, 2004). The subtest adheres to the underlying constructs of the revised multi-component WM model proposed by Baddeley and colleagues reviewed in Chapter 3. Making reference to the central executive of the revised multi-component model of WM, this component was assessed using the DSB subtest. The DSB task was briefly described in Chapter 3, and requires participants to reorder digits heard according to the identified rule, which here is to recall digits in reverse sequential order. The task requires minimal attentional resources or inhibitory control processes, so is a robust measure of WM (Diamond, 2013). Since children commonly make errors recalling three digits, the 2-item practice trial is followed by the 2-item test trial. If the child responds correctly the 3-item practice trial is presented followed by subsequent test trials. The mean test-retest reliability co-efficient from the test manual is .80. Test administration is approximately 10 minutes for each participant

5.8.2.2 Rationale and selection of primary outcome measure of fluid reasoning

Of particular note from EF research is the separability and convergent validity of WM and FR (Conway et al. 2003; Diamond, 2013; Kane & Engle, 2002). Study 1 hypothesises that in light of this evidence, improvements in WM as a result of computerised training, would be expected to transfer to improvements in FR.. However, as discussed in Chapter 3, while tasks of matrix reasoning are considered some of the best measures of FR, recommendations from research studies to date strongly advise not using a single measure of FR (Raven, 2000) due to the possibilities of task 'impurity' (Booth et al. 2010). Therefore, a conservative approach is taken in this study by selecting two tasks of FR.

The primary measure of FR selected in this study is the Matrix Reasoning task (MR) (Weschler, 2004). The mean test-retest reliability coefficient for this test from the manual is .89. The subtest requires children to manipulate rules and apply logic to choose the missing picture from a selection to complete the conceptual pattern. The test accesses children's visuospatial reasoning (i.e. visuospatial sketchpad), attention, inhibition and planning, all of which contribute to WM (Booth et al. 2010; Cowan et al. 2005; Diamond, 2013). Administration of the test is approximately 10 minutes per participant. The secondary measure of FR task is discussed later in this chapter.

5.8.2.3 Rationale and selection of the primary outcome measure of numeracy

The Basic Number Screening Test (Gillham, Hesse & McCarty, 2012) is a standardised measure of numeracy for children aged between 6-12 years. The test samples a comprehensive range of procedural and conceptual understanding ranging from number knowledge, skills and mental operations using two parallel forms applied at pre-test (Form A) and post-test (Form B) to reduce retest effects. The authors advise administration with individuals or small groups (maximum of ten children). In this study, administration is in small groups by the author, with approximately seven children per group, for 30 minutes. The standardised score indicates the child's general level of numeracy ability. This measure has a test-retest reliability co-efficient .94. The format of the test circumvents any disadvantage to children with WM difficulties since the test is read to the participants by the author, and response forms combine visual diagrams and written text.

5.8.2.4 Rationale and selection of the secondary outcome measure of fluid reasoning

The *n*-Back task (Holmes et al. 2009; Jaeggi et al. 2010) was selected as a secondary outcome measure of FR to support triangulation of the findings gained from the primary outcome measure using the MR task. Internal reliability of the 2-back task selected for use in this study, as measured by Cronbach's Alpha, is variable, ranging from $\alpha = .16$ to .91. More complex variants of this task yielding higher reliability (Jaeggi et al. 2010; Van Leeuwen, Van den Berg, Hoekstra & Boomsma, 2007).

Findings from correlation studies to date using the *n*-Back task as a new measure of WM are inconclusive with weak correlations reported to traditional WM tasks, such as complex memory span tasks (Jaeggi et al. 2010; Redick & Lindsey, 2013). Weak results may be surprising, with some researchers arguing that components of the revised multi-component model of WM are harnessed by the *n*-Back task, including storage and processing information (Baddeley, 2007). Conversely, others suggest the results are as expected since the task does not access complex WM processes (i.e. storage and processing), but only recognition processes (Lendínez, Pelegrina & Lechuga, 2015). Notwithstanding the two polarising arguments, findings to date may be confounded by methodological limitations arising from the use of various measures of WM across studies (Morrison & Chein, 2011), and there being no standard procedure for administering the *n*-Back task across studies. Nonetheless, the *n*-Back task is found to have strong convergent validity with FR tasks (Jaeggi et al. 2010), and thus selected as a secondary outcome measure of FR in this study. Further, by selecting this task, the study aims to add to the existent evidence base on its use as a measurement item with children to evaluate possible training-transfer effects from computerised training programmes to FR, since use of only one measure of FR is ill-advised (Raven, 2000).

The version of the *n*-Back task selected here involves pupils being tested individually using a computerised E-Prime 2.0 software version of the task provided by the University of Strathclyde (Schneider, Eschmann & Zuccolotto, 2012). The task is *2*-back with numerical digit strings presented in the centre of the screen for 500ms. Other variations of the task may present letters, drawing or words on the screen. A description of the *n*-Back task is provided in Chapter 3. The software records individual responses times (RT), or the time each participant takes to complete the full set of trials, and total correct scores (TS), or the number of accurate responses in the full set of trials. Administration time for each child is approximately 30 minutes, and requires adult supervision.

5.9 ANALYSIS

Quantitative data was analysed using the Statistical Package for Social Sciences (SPSS) Version 21 (IBM, 2012).

5.9.1 Missing Data

No data was missing at the pre-test phase. Missing data at post-test phase was replaced with pre-test scores. This approach was selected rather than multiple imputation as it provides a conservative method of both addressing missing data as a possible source of bias (Field, 2013) and is consistent with the aims of this study which is to account for any change in scores between pre-test (T1) and post-test (T2) phases across intervention conditions relative to a control condition (Dugard, Todman & Staines, 2010).

5.9.2 Scoring

(a) Primary outcome measures

Scoring of the all primary outcome tasks followed the scoring instructions within the individual test manuals to provide standardised scores or scaled scores for each participant. The WISC-IV (Weschler, 2004) provides a scaled score for WM based on the combined raw scores of the DSB and Digit Span Forwards (DSF) tasks. As aforementioned, this study selects the DSB as the primary outcome measure of WM and this task was scored independently of the DSF rather than combining both subtests as advised in the WISC-IV scoring manual (Weschler, 2004). Instead, each participant's raw score for the DSB was multiplied by two, with the raw score next transformed into a scaled score using the norm conversion tables in the WISC-IV manual as is standard scoring protocol. For numeracy performance, as measured by the Basic Numeracy Screening Test (Gilham et al. 2012) each child's raw score was converted using the norm tables to provide a standardised score as a measure of their numeracy competency.

(b) Secondary outcome measure

E-Prime 2.0 (2012) software version of the *n*-Back task provided by the University of Strathclyde provided responses times (RT) and total accurate responses to each item in the presented trial, or total scores (TS) for each participant, which were used in the statistical analysis of this study.

(c) Inter-scorer reliability

All measures and test papers were scored using double-blind marking with participants assigned a random ID number. The tests were first scored twice by the author and then by a research assistant and accuracy was 100% (Brooks, 2004).

5.9.3 Rationale for quantitative data analysis strategy

The first part of this section details the rationale for the quantitative data analysis strategy then an overview of the dilemmas and risks of the different data strategies informs selection of the statistical methods used in Study 1.

To summarise, this study is designed to determine whether participants' performance scores on tasks measuring WM capacity, FR and numeracy, improve or change from pre-test (T1) to post-test (T2), relative to both non-active and active control conditions as described at the outset of this chapter. The main theoretical positions on change in pre- and post- intervention research studies pose two distinctive questions:

1) Whether the mean scores of the intervention condition are improved at post-test, following the intervention or treatment, or
2) Whether the mean scores of the intervention condition change from pre- to post- test following the intervention or treatment, and what is the nature of the change.

The primary research question for Study 1 follows the form of (2) above.

5.9.3.1 Positions on the analysis of covariance and change score analysis

In the case of the first research question, the emphasis is on the end product or post-test score. This question is often the domain of RCT described earlier (Oakes & Feldman, 2001; Torgerson & Torgerson, 2008; 2013). Conclusions from the literature posit that studies concerned with the first question are well-advised to explore the change between groups using the statistical procedure of analysis of covariance (ANCOVA) (Dugard et al. 2010; Fitzmaurice, Laird & Ware, 2004; Oakes & Feldman, 2001; Vogt, 1999). Use of the ANCOVA is sparingly advised and usually for RCT (Owen & Froman, 1998; Vogt, 1999). The ANCOVA has attractive statistical attributes since the test:

- provides advantages in power analysis, being sufficiently sensitive to adjust the post-test scores by minimising any baseline differences across the data set (Field, 2013)
- reduces the variance within conditions to eliminate confounds (Dugard et al. 2010)
- accounts for between-group differences at post-test, rather than relative gains or changes across conditions (Knapp & Shafer, 2009).

While the analytical strategy to answer the first type of research question is more straightforward, answering the second type of question, which is the form this study takes, is more complex. Some researchers advocate using the ANCOVA to answer research questions concerned with changes in scores (or what is commonly referred in the literature as gain or change score analysis), and not purely for use in RCT designs (Maxwell & Delaney, 1990; Senn, 2006).

Typically, change score analysis tests the null hypothesis of no difference between conditions (Field, 2013), since the change score itself computes the differences between each participants' pre- and post-test scores. The change score controls for individual participant differences in the pre-test scores by measuring the post-test score relative to each participants' pre-test score. Rogosa (1988) argues that the change score provides an unbiased estimate of change, since it can only detect individual differences that actually exist, and unlike the ANCOVA test, does not use residual changes from the pre-test scores as a covariate for adjusted post-test scores. Although, the change score does not control for differences in the pre-test scores between groups, independent statistical checks of the baseline data (discussed later) to rule out baseline differences can be legitimately employed (Fitzmaurice et al. 2004).

With change score analysis selected as the most robust statistical strategy available for this quasi-experimental study, the properties and drawbacks of the ANOVA are considered. The ANOVA has a number of assumptions which must be met to qualify its use and strengthen the case for statistical conclusion validity (Cook & Campbell, 1979) and include: (a) the sample must be of sufficient size (i.e. greater than n = 10) to provide adequate statistical power; (b) conditions or groups are randomly allocated and from which it is expected that any differences are normally distributed in terms of errors of measurement and individual differences; and (c) that any differences across the data set are somewhat homogenous, indicating that the differences are uniformally distributed across the dataset (Field, 2013).

However, these quandaries surrounding selection of change score analysis, using ANOVA, versus an ANCOVA approach to statistical analysis, may be more apparent than real. Maxwell & Delaney (1990) argue that distinctions between both data analysis strategies are unnecessary, since when there are equivalent groups at baseline, both are essentially similar. These researchers (*op. cit.)* even support the use of change score analysis for some RCT. The ANCOVA is reported to hold more statistical power than change score analysis as it has an additional degree of freedom. Despite this, the author returns to the fundamental aim underpinning this study, which is to detect any training-transfer effects on children's WM or numeracy skills following computerised training programmes, and to determine the nature of any changes. Hence, given the ANCOVA test of adjusted post-intervention scores does not provide information about how conditions may have improved, change score analysis provides this information in a form which supports the interpretation of any improvements into practice for schools (Rogosa, 1988). Therefore, change score analysis has been selected as the main analytical strategy of this study and is reported in the next chapter.

5.9.3.2 Baseline checks on data

As described in the previous chapter, change score analysis does not control for baseline difference between conditions, which require independent statistical checks (Fitzmaurice et al. 2004) to establish any non-equivalence of groups, a basic threat to validity (Cook & Campbell, 1979). Accordingly, baseline checks are carried out using multiple pairwise comparisons of the univariate ANOVA (Field, 2013).

5.9.3.3 Rationale for planned analyses

Post-hoc multiple pairwise comparisons are selected to explore the source of any statistically significant differences that are predicted, and to minimise the likelihood of the familywise error, or Type 1 error, which identifies false positives in the data set. Caution is required when making multiple pairwise comparisons, since this increases the error rate, which poses a threat to statistical conclusion validity (Cook & Campbell, 1979). To minimise threats to validity, both Bonferroni-corrections test and Tukey tests are conservative tests used to control for possible error rate when there is multiple testing (Field, 2013). However, the Bonferroni-corrections is widely used when sample sizes are unequal and provides a more conservative measure by which to control for Type I error rate as the number of multiple pairwise comparisons increase (Field, 2013).

STUDY 2: DEVELOPMENT AND VALIDATION OF THE PUPILS' PERCEPTIONS OF NUMERACY QUESTIONNAIRE (PPNQ)

5.10 RATIONALE AND AIMS

Study 2 aimed to establish a useful method of gathering primary-aged school pupils' perceptions of numeracy and to then illuminate findings from Study 1 with children's perceptions of numeracy using the Pupils' Perceptions of Numeracy Questionnaire (PPNQ). The PPNQ is a short scale developed and validated for this thesis.

5.10.1 DESIGN

A between-subjects repeated measures design (Robson, 2011) was used to compare children's perceptions of numeracy using the Pupils' Perceptions of Numeracy Questionnaire (PPNQ) across time point (pre-versus post-intervention) for all three conditions. The independent and dependent variables of the study are shown in Table 13 below:

Table 13

Summary of the independent and dependent variables for Study 2

<table>
<tr><th>Dependent variables
(Variables being measured)</th><th>Independent Variables</th></tr>
<tr><td rowspan="2"><u>Perceptions of numeracy</u>
Ratings on Pupils' Perceptions of Numeracy Questionnaire</td><td><u>Time point</u>
Pre-intervention stage (T1)
Post-intervention stage (T2)</td></tr>
<tr><td><u>Condition</u>
Computerised WM (Condition 1)
Computerised Numeracy (Condition 2)
Non-active control (Condition 3)</td></tr>
</table>

5.10.2 Ethics

As in Study 1

5.10.3 Consent

As in Study 1

5.11 INSTRUMENTATION

5.11.1 Candidate Instrumentation

Measures used in the literature to gather children's perceptions of numeracy include focus groups (Ashby, 2009). However, this study is informed by the principles of universal intervention as described in Chapter 1, and aims to measure all participants' perceptions of numeracy, hence a questionnaire is selected.

Review of the literature highlights a dearth of instruments to measure younger children's perceptions of numeracy. A summary of the most commonly used instrument follows, alongside strengths and limitations.

5.11.1.1 Questionnaires Considered

5.11.1.1.1 Modified Fennema-Sherman Attitude Scale

The literature highlights the Modified Fennema-Sherman Attitude Scale (Doepken, Lawsky & Padiva, 2009) as a robust measure of children's perceptions and attitudes towards numeracy. The instrument is a 28-item questionnaire with a robust Cronbach's alpha reliability coefficient of .92. Standardised on American samples, the item is designed for older children. Review of the structure indicates an open-ended rating format using the 5-point Likert Scale to rate items which cover four themes including: personal confidence, usefulness of numeracy, perceptions of the class teacher and male performance in numeracy. Several limitations of the instrument include the complexity of the language used which would be too difficult and abstract for use with the younger participants in this study; the length of the questionnaire and time it takes for the individual participant to complete it, particularly if the measure is used as a pre-post comparison, as participants would be required to complete the questionnaire twice. Further, the questionnaire is not free to download, and so would incur additional costs which are out with the scope of this study. Therefore, the instrument would not meet the needs of the current study or its participants.

5.11.1.1.2 Maths Anxiety Questionnaire (MAQ)

The Maths Anxiety Questionnaire (Thomas & Dowker, 2000) is a 24-item instrument used to measure children's anxiety towards numeracy. It is used extensively in international research with primary school-aged pupils and is translated into numerous languages (Galla & Wood, 2012). The items combine into four subscales: self-perceived performance, attitudes in mathematics, unhappiness related to problems in mathematics and anxiety related to problems in mathematics. Children answer questions in four different formats which include: "*How good are you at…",* "*How much do you like*….", *How happy or unhappy are you if you have problems with*…." and "*How worried are you if you have problems with*…." Responses are facilitated by supportive figures comprising the 5-point Likert Scale, coded 0 to 4, where the higher score denotes maths anxiety. The instrument has a Cronbach's alpha reliability coefficient value range between .83 and .91. Administration of the MAQ lends itself to individual or group, and takes approximately 10-15 minutes to complete.

Review of the MAQ indicated that the focus of the questionnaire is perhaps too narrow for this study, since its four subscales were directed towards the construct of 'maths anxiety' (Galla & Wood, 2012). The focus of this study is not predominantly maths anxiety, but to explore perceptions towards numeracy and its delivery in the school curriculum. Further constraints of the MAQ for use in this study, include the level of language used in individual items, which would likely present barriers to approximately 10% of the sample in the study, with seven children having English as an Additional Language across the three conditions. For example, some items contain several clauses and / or ask the child to think abstractly: "*How worried are you if…. How happy or unhappy are you if*….." The questions themselves may elicit feelings of worry should the children struggle to understand the wide range of question formats used. Further, the wide choice of a 5-point Likert Scale may also create practical difficulties for the author who would administer the item in small groups using the lock step method. A 28-item instrument is considered too long for the younger age of this sample to concentrate throughout the administration.

5.11.1.1.3 Pupils' Perceptions of Numeracy Questionnaire (PPNQ)

A task group (Toseland & Rivas, 2005) was formed with the author and the class teachers from each of the three conditions. The task group was used as a precautionary measure to enhance reliability and validity of the questionnaire by way of reviewing the questionnaire for clarity of composition and intent of items, and to identify those items which to be retained, adapted or excluded before it is administered with the younger participants of this study. Unfortunately, time constraints meant it was not possible to expand the task group to include a range of members from diverse backgrounds, as suggested by Toseland & Rivas (2005), which may have limited the design of the item.

As a universal intervention approach is the focus of this study, a much simpler questionnaire structure would be required than the MAQ. Indeed, research studies indicate that when completing longer scales, children's ratings can become more positive over the course of the scale. For example, Dowker, Bennett & Smith (2012) devised the bespoke Maths Attitude and Anxiety Questionnaire and concede that with longer scales there is ambiguity over whether a rating reflects an accurate view, or a preference. Therefore, the task group agreed to focus on a brief instrument with the simplest of language.

The task group discussed the possible bias that may emerge from the author administering the questionnaire with the children (Robson, 2011). Practical constraints in the school timetable were also discussed, which meant that the class teachers would be unable to administer the questionnaires to their class. There are potential sources of bias whether the class teacher or author administered the questionnaire. Additionally, the task group discussed the characteristics of the children and recognised there would be a need to focus on minimising socially desirable answers with the use of considered questionnaire items. Consequently, items were kept brief and language simple for children to understand (Fraser et al. 2004). Items were neutrally and negatively worded to elicit thoughtful and considered responses from children, rather than a format where children could merely agree to positive statements and provide socially desirable answers. Further, items offered binomial response choice to obtain factual neutral or negative responses. For example, children responded to each item with anchors either "*Like me*" or "*Not like me*". Binomial anchors supported by cartoon characters were identified to engage children. Previous research indicates the use of facial expressions / cartoon characters in questionnaires is engaging for children and may minimise any language barriers, especially for the younger children participating in this study (Flockton & Crooks, 1997).

However, caution is equally required using these anchors with a binomial scale. The validity of positive responses may be questionable as responses may not reflect accurate perceptions, but merely reflect the most attractive cartoon / facial expression that appeals to the children at the time. A 5-point Likert Scale comprised of facial expressions was discussed by the task group, but considered too confusing for the children in this study. Specifically, there was disagreement in the group about whether a rating of '3' on each item represented a neutral score. Thus, the PPNQ uses binomial ratings as described above and included 2 practice items immediately followed by 6 test items. Higher scores represent more negative perceptions of numeracy.

The task group used the taxonomy derived from the literature presented in Table 1, to highlight themes of interest in the design of the PPNQ test items. Themes included: children's self-ratings of numeracy, their liking of numeracy, anxiety about numeracy, unhappiness about poor performance and perceptions of class teacher instruction. Six items for the PPNQ were identified with a general focus on the psychosocial and socio-emotional attitudes of children towards numeracy and their perceptions of class teacher instruction. The selected 6 items are shown in Table 14 below and the item itself in Appendix D:

Table 14

Items from the Pupils' Perceptions of Numeracy Questionnaire

Item	Statement
1	Some kids find number hard
2	Some kids hate number
3	Some kids worry about number
4	Some kids do not understand what the teacher says in number
5	Some kids do not like doing number on the computer
6	Some kids get sad if they do badly in number

5.12 ANALYSIS

5.12.1 Principal Components Analysis

As this study is the first to investigate the underlying structure and dimensionality of the PPNQ, exploratory Principal Components Analysis (PCA) (Tabachnick & Fidell, 2007) was used to determine components of the pre-intervention scores on the scale.

5.12.2 Missing Data

Missing data for the PPNQ was found at pre-test: three pupils did not complete the PPNQ due to absence, and post-test: six pupils did not complete the PPNQ due to absence, including the extended absence of some Polish pupils.

SPSS does not permit PCA where missing data has been imputed by multiple imputation (MI) procedures (IBM, 2012). To address this, PCA were first carried out on completed cases and factor scores computed. Missing values were then imputed using estimation maximisation (EM) procedures (IBM, 2012). In the case of pre-intervention scores the three missing factor scores were estimated using all quantitative variables, excluding the PPNQ scores themselves. In the case of post-intervention scores, the same procedure was followed for the six missing scores, which were spread equally across the 3 conditions.

5.12.3 Scoring

Children provided a Yes or No response rating for each item of the PPNQ, with higher ratings indicating more negative perceptions of numeracy. For scoring purposes, a response of "*Like me*" – computed a score of 1, "*Not Like Me*" – a score of 0. The total rating score for each child was used in the statistical analysis.

STUDY 3: PARTICIPANT EVALUATION OF TWO COMPUTERISED TRAINING PROGRAMMES

5.13. RATIONALE AND AIMS

Study 3 aims to investigate the implementation issues to add precision to findings from Study 1 and 2. Study 3 comprises two parts, Part 1 explores the accessibility and feasibility of computerised training programmes for the main participants, the primary-aged school pupils. Part 2 investigates implementation issues of the intervention for the class teachers.

5.14 PART 1: PUPILS' EVALUATION OF COMPUTERISED TRAINING PROGRAMMES

5.14.1 DESIGN

A case study design using focus group methodology was utilised to gather children's views at post-intervention to determine the acceptability and feasibility and any perceived impact of the computerised training programmes

5.14.2 Ethics

As before

5.14. 2 Consent

As before

5.15 METHODOLOGY

5.15.1 Participants and recruitment

At post-test phase six pupils from each training condition were selected using random sampling to participate in the focus groups (Robson, 2011) using names from a hat. The sample was balanced for gender, and where required, names were returned to the hat until the selection achieved a 50% gender balance. Research studies of focus group methodology recommend between 6-12 participants is adequate (Littoselletti, 2003; Wilkinson, 2011) and details for each focus group are provided in Table 15.

Table 15

Pupil focus group details

Focus Group	School	Participants	Facilitator	Duration
1	Computerised WM training condition	6 (3 boys, 3 girls)	Author	40 minutes
2	Computerised numeracy training condition	6 (3 boys, 3 girls)	Author	30 minutes

5.16 ANALYSIS

Focus group methodology is selected as it fits well with the study aims to gather participants' views and experiences of an intervention. Further, focus groups facilitate gathering unique data from informal discussion and interaction between participants (Kitzinger, 1994; Smith, 2015); a feature which is particularly relevant to providing a naturalistic interaction among primary-aged school children who are the participants of this study. The focus group schedule is provided in Appendix E.

As part of the implementation audit pupils were encouraged to maintain a log book, as provided by Memory Quest Flex (Junior) and adapted by the author for use by pupils receiving the computerised numeracy training programme, since the Study Ladder numeracy programme did not provide a pupil log book. Both versions of the log book are contained in Appendix G. The purpose of the pupil logbooks was to provide each individual pupil with a daily, visual reinforcement of their progress and it was anticipated that pupils might reflect on the logbook during the focus group activities.

5.16.1 Thematic analysis

Thematic analysis is utilised to analyse the focus group data as it is a well-established, systematic technique in qualitative research (Smith, 2015; Miles, Huberman & Saldana, 2014). Thematic analysis methodology supports the aims of this study to explore the implementation of the intervention with the sample population (Willig, 2001). A broadly experiential approach to thematic analysis is considered the most appropriate strategy to understand pupils' experiences of the computerised training programmes. A semantic and deductive approach to coding and analysis was used which means that both participants' experiences / meaning, and prior theoretical frameworks derived from the research literature are central to the process (Smith, 2015). Connolly et al.'s (2009) framework for the evaluation of computerised learning programmes is used as the prior theoretical framework to facilitate coding and analysis of focus group data. A diagrammatic summary of Connolly et al.'s (2009) evaluation framework is shown in Figure 11.

Conventional thematic analysis entails using a coding scheme to synthesise the data set and derive themes and sub-themes to explore and understand the data. The six phases of thematic analysis outlined by Braun & Clarke (2006) are utilised in this study and shown in Table 16. An overview of the phases employed include: familiarisation with the data; coding of similar data features or patterns; searching for themes from those patterns identified previously; reviewing themes; defining and naming themes; and synthesis of themes to understand the data set.

Table 16

Process of each of the six phases of thematic analysis

Braun & Clarke's (2006) phases of thematic analysis	Description of the process
Phase one: Familiarising yourself with your data	• Transcribed notes • Checked transcriptions • Re-read the data sets • Initial ideas noted
Phase two: Generating initial codes	• Systematically coded entire data sets by selecting extracts by hand and creating groups of potential themes • Inter-rater reliability checks carried out using blind colleague to code 10% of each transcript – 95% reliability achieved
Phase three: Searching for themes	• Grouped the potential themes using the Connolly et al. (2009) evaluation framework to facilitate grouping initial codes into themes • Overlap of themes evident at this stage
Phase four: Reviewing themes	• Review themes using the Connolly et al. (2007) evaluation framework for computerised learning to ensure discrete themes, no overlap or repetition • Generated a thematic map
Phase five: Defining and naming themes	• Re-read quotes extracted from transcription to ensure themes capture important information in relation to the research questions • Use Connolly et al.'s (2009) framework as above to name themes using concise names • Inter-rater reliability checks carried out using an independent colleague to code 10% of each transcript – 96% reliability achieved.
Phase six: Producing the report	• Final analysis to extract most appropriate quotes to indicate themes and that themes cover essence of participants' experiences • Cross-referenced themes with Connolly et al.'s (2009) framework and wider literature review and reorganised themes if necessary • Recorded data analysis in the results section

5.17 PART 2- CLASS TEACHER EVALUATION OF COMPUTERISED TRAINING PROGRAMMES

5.17.1 RATIONALE AND AIMS

To investigate methodological and practical issues likely to impact upon the implementation of computerised training programmes, specifically to test the accessibility and feasibility of computerised training programmes with primary school staff.

5.17.2 DESIGN

A case study design was utilised to gather class teachers' views at post-intervention to determine the acceptability and feasibility and any perceived impact of the computerised training programmes.

Thematic analysis methodology was used to gather data from training schedules completed throughout the intervention and from impact questionnaires completed at post-test follow-up to triangulate qualitative data.

5.17.3 Ethics

As before

5.17.4 Consent

As before

5.18 METHODOLOGY

5.18.1 Participants and Recruitment

Class teachers from both intervention conditions (*N*=2) completed the training schedule and impact questionnaires.

5.19 INSTRUMENTATION

5.19.1 Training schedule

The implementation audit also comprised training schedules. Staff were encouraged to maintain training schedules as a log of training throughout the 7-week implementation phase (Appendix H). Training schedules included detailed information about the date, time and duration of all training sessions, as well as important observational information about children's engagement and motivation with the training programmes as these are important variables for the implementation of computerised training programmes (Boyle et al. 2013; Connolly et al. 2009; Connolly et al. 2012).

5.19.2 Impact questionnaires

Impact questionnaires were selected as another element of the implementation audit to provide information from staff about their perceived outcomes of the intervention and its implementation. The impact questionnaire used in this study was provided in the logbook for Memory Quest Flex (Junior) and adapted for use with the class teacher of the Numeracy Condition. The impact questionnaire provided a mixed methods approach which gave staff opportunity to make qualitative responses and quantitative ratings using a Likert Scale design (Appendix I).

5.20 ANALYSIS

Thematic analysis was utilised to analyse the class teacher training schedules and impact questionnaires as per the analysis and used in Part 1 of this study. To aid the reader make sense of the messages of class teachers' entries in the training schedules, only distinctive information or information that extended themes gathered from the pupil focus groups is included for analysis. Additionally, for clarity of reporting only qualitative information from the impact questionnaires is reported in the analysis.

5. 21 CONCLUDING REMARKS

The purpose of this chapter was to describe the research methodology and instrumentation process for the study. Selection of a quasi-experimental research design with school as a nested factor, has been defended and the threats to validity and reliability explicated for later interpretation. Standardised and reliable measures of WM, FR and numeracy skills are selected to answer those research questions concerned with the efficacy of the intervention. Questionnaire, interview and case study methodologies have been identified to answer those research questions concerned with the intervention in practice. A comprehensive implementation audit and data analysis strategy has been presented to support the triangulation process to inform accurate and consistent interpretations about the efficacy, acceptability and feasibility of computerised training programmes in mainstream education settings in the Scottish context.

The following three chapters now present the procedure and results for each study in turn.

CHAPTER 6: RESULTS AND ANALYSIS

STUDY 1: EVALUATION OF TWO COMPUTERISED TRAINING PROGRAMMES

Study 1 rationale and aims, design and instrumentation were presented in Chapter 5.

6.1 PROCEDURE

To orientate the reader, the procedure for Study 1 is illustrated in Figure 12.

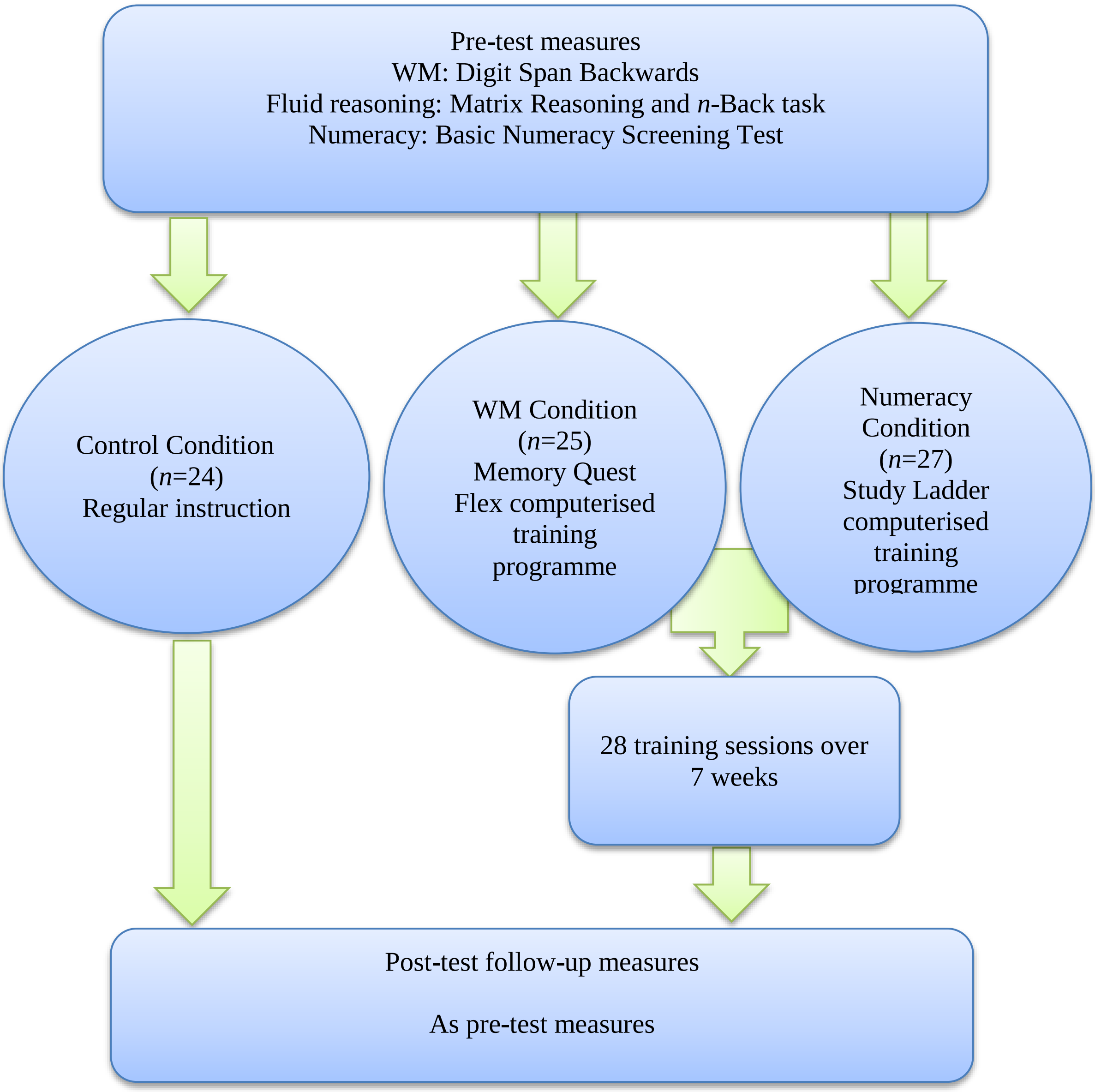

Figure 12: Study 1 procedure

6.1.1 Staff training

(a) Training for Coaches

Both computerised training conditions required a coach to implement and co-ordinate the training programme. In both schools, the coach was the class teacher (*N* = 2). The author adapted the staff coaching guidance offered by the Memory Quest Flex (Junior) manual. Instead of a one-off training session with the nominated coach (responsible for co-ordinating the training), an initial ½ day coaching was delivered by the author with class teachers in both intervention schools on each of the computerised training programmes. The aim of the coaching session was to:

- support staff prepare the learning environment
- provide practical demonstration sessions to understand and navigate the user interfaces
- identify how programmes were to be implemented i.e. agree time of day and how often training to be delivered
- offer space for staff trouble-shooting i.e. how to manage technology difficulties, or supports to re-engage children with training if required.

The one-off coaching session advised by the manual for Memory Quest Flex (Junior) was expanded by the author to provide a pre-arranged gradual modelling and consultation approach to aid phased independent facilitation of the programmes by the class teachers, consistent with the coach-consult method (Balchin, Randall & Turner, 2006). This approach was selected to support staff embed training routines into daily practice, and perhaps embed the training as a sustainable intervention in both schools (Fixsen et al. 2005). Therefore, the agreed coaching model was for the author to support the class teachers: the first week of intervention; reduce this by

50% in the second week; provide a check-in for one session over the next two weeks, and then for sessions to be independently led by the class teacher the remaining weeks. This expanded coaching approach was replicated for the numeracy condition.

The author was also available to the class teachers during weekly school visits and by e-mail or phone. No teacher chose to make contact by e-mail or phone.

(b) *n*-Back task training

The procedure for the *n*-Back in this study was that two classroom assistants in each of the three participating schools received training from the author on the use of the E-Prime programme on a laptop provided by the University of Strathclyde to administer the *n*-Back task. By pairing the training, the task would not be disrupted by possible staff absence. Classroom assistants in each of the three conditions then agreed to facilitate sessions with individual children at the pre- and post- intervention follow-up phases.

6.1.2 Pupils

Pupils completed either (a) a 7-week computerised WM training programme, Memory Quest Flex Junior (*n*=25); or (b) a 7-week computerised numeracy training programme, Study Ladder (*n*=27), both relative to (c) a non-active control condition receiving only their regular curriculum instruction (*n*=24). Both computerised training programmes were implemented in both schools at the same time over the 7-week intervention period. Further details about the instrumentation, including pupil log books can be found in Chapter 5.

Pupils completed pre-test assessment measures, and the same measure was completed at post-test follow-up phase, which was three weeks after completion of the 7-week computerised training programme; a timescale in line with Chacko et al. (2014) to determine any maintenance training-transfer effects. For pre- and post-intervention, all pupils were:

a) Tested individually in one aspect of WM memory and one aspect of fluid reasoning using standardised subtests from the WISC-IV. The order of presentation of tasks for each pupil was different to control for any order effects. The tests took approximately 20 minutes to administer by the author.
b) Tested in small groups (*n*< 10) by the author for numeracy skills using the Basic Numeracy Screening Test (Gilham et al. 2012), following administration guidance in the manual. The test was administered by the author in the lock-step method, with each question read aloud with pupils progressing through the test simultaneously. The test takes approximately 20-30 minutes to administer.
c) Tested individually on a computerised task of FR (i.e. *n*-Back task) by a classroom assistant. The duration of testing varied between 30-40 minutes for each child.

To minimise potential barriers of reading ability, all instructions were read to the pupils by the author.

6.2 RESULTS

Study 1 results are reported for (a) descriptive statistics; (b) preliminary data inspection; (c) training-related changes in pre- to-post-test performance scores; (d) the standardised effect sizes of the training-related changes; (e) analysis of gender effects across the data set; and (f) analysis of gender effects.

(a) Descriptive statistics

Means, standard deviations and differences between pre- and post-intervention mean scores for each of the dependent variables (performance on DSB, MR and Numeracy, *n*-Back tasks) for the three conditions (Condition 1- Computerised WM, Condition 2- Computerised Numeracy, Condition 3- Control) are shown in Tables 17-21.

Table 17

Descriptive statistics for Digit Span Backwards (DSB) task performance across Conditions

Condition		Pre DSB	Post DSB
WM Cond	N	25	25
	Mean	8.92	9.80
	Std. Deviation	1.78	1.94
	Skewness (*z*-scores)	0.70	0.14
	Kurtosis (*z*-scores)	-.14	-1.30
Numeracy Cond	N	27	27
	Mean	8.52	8.37
	Std. Deviation	1.48	1.42
	Skewness (*z*-scores)	.86	1.32
	Kurtosis (*z*-scores)	-.18	.25
Control Cond	N	24	24
	Mean	8.54	8.37
	Std. Deviation	2.0	1.88
	Skewness (*z*-scores)	.80	.72
	Kurtosis (*z*-scores)	-.55	-.97

Table 18

Descriptive statistics for Matrix Reasoning (MR) task performance across Conditions

Condition		Pre MR	Post MR
WM Cond	N	25	25
	Mean	7.52	9.48
	Std. Deviation	1.42	1.96
	Skewness (*z*-scores)	-1.43	-1.06
	Kurtosis (*z*-scores)	.65	-.92
Numeracy Cond	N	27	27
	Mean	8.11	8.26
	Std. Deviation	1.69	1.58
	Skewness (*z*-scores)	.95	.65
	Kurtosis (*z*-scores)	-.16	.047
Control Cond	N	24	24
	Mean	7.83	7.87
	Std. Deviation	1.86	1.68
	Skewness (*z*-scores)	1.22	1.22
	Kurtosis (*z*-scores)	-.089	.12

Table 19

Descriptive statistics for Numeracy task performance across Conditions

Condition		Pre Numeracy Task	Post Numeracy Task
WM Cond	N	25	25
	Mean	82.1	83.1
	Std. Deviation	5.00	4.51
	Skewness(*z*-scores)	-1.12	.90
	Kurtosis (*z*-scores)	-.90	-.25
Numeracy Cond	N	27	27
	Mean	83.6	84.2
	Std. Deviation	4.79	4.93
	Skewness(*z*-scores)	.16	.15
	Kurtosis (*z*-scores)	-1.24	-1.16
Control Cond	N	24	24
	Mean	84.1	82.8
	Std. Deviation	12.0	8.77
	Skewness(*z*-scores)	3.05	1.53
	Kurtosis (*z*-scores)	1.86	-.11

Table 20

Descriptive statistics for Total Score (TS) *n*-Back task performance across Conditions

Condition		Pre TS n- back	Post TS n-back
	N	25	25
	Mean	23.7	25.2
WM Cond	Std. Deviation	3.8	2.7
	Skewness (*z*-scores)	-.51	-1.52
	Kurtosis (*z*-scores)	-.80	.24
	N	27	27
	Mean	22.3	25.1
Numeracy Cond	Std. Deviation	4.54	3.69
	Skewness (*z*-scores)	-1.09	-5.21
	Kurtosis (*z*-scores)	-.072	8.73
	N	24	24
	Mean	25.8	25.7
Control Cond	Std. Deviation	5.32	4.65
	Skewness (*z*-scores)	-5.28	-3.29
	Kurtosis (*z*-scores)	8.46	1.90

Table 21

Descriptive statistics for Response Time (RT) *n*-Back task performance across Conditions

Condition		Pre RT n- back	Post RT n-back
WM Cond	N	25	25
	Mean	67.3	49.9
	Std. Deviation	25.9	29.6
	Skewness (*z*-scores)	1.37	2.86
	Kurtosis (*z*-scores)	1.16	1.91
Numeracy Cond	N	27	27
	Mean	71.5	80.4
	Std. Deviation	24.6	156
	Skewness (*z*-scores)	.72	10.5
	Kurtosis (*z*-scores)	-.51	26.6
Control Cond	N	24	24
	Mean	80.4	83.3
	Std. Deviation	20.8	26.7
	Skewness (*z*-scores)	-.70	.087
	Kurtosis (*z*-scores)	3.25	1.23

Preliminary inspection of the dependent variables shows that from T1-T2 across the three Conditions for all primary outcomes measures (DSB, MR and Numeracy tests) performance scores do not show significant patterns of marked skew or kurtosis, with scores within the average range between -1.96 and 1.96 (Field, 2013). Marked positive skew is noted in the Control Condition for the T1 numeracy test performance scores (z = 3.05), but by T2 returns within normal range (z = 1.53). The performance scores for all Conditions on the *n*- Back task, a secondary outcome measure, exhibited signs of marked positive kurtosis by T2, indicating leptokurtic distributions marked by heavy tails and higher peaks (Field, 2013). Further preliminary data inspections on the distributions were carried out and reported in the next section.

Descriptive statistics show improved mean scores on all dependent variables for the WM Condition. The Numeracy Condition displays improved mean scores on the Numeracy, MR and TS *n*-Back task. However, the Numeracy Condition shows reduced mean scores on the DSB; an unexpected result, and with slower performance in RT *n*-back task at T2. The Control Condition fairs least well relative to the two training conditions, with improved mean scores observed only on the MR task, and reduced performance on the other dependent variables. It is important to note at the outset that the Control Condition experienced a change in class teacher mid-way through the intervention, which introduces history bias and threatens internal validity (Cook & Campbell, 1979; Robson, 2011), which is considered briefly in the summary section.

(b) Preliminary data inspection

Preliminary data analysis of baseline (T1) data was carried out to establish any between-group differences since group non-equivalence poses a primary threat to validity (Cook & Campbell, 1979). Also, any non-equivalence characteristics would inform the selection of further analyses. Univariate analysis of variance (ANOVA) tests were applied to determine whether there were significant T1 differences between the 3 Conditions for each of the dependent variables: DSB, MR, Numeracy and *n*-Back task. There were no significant differences in performance at T1 for the

DSB task (*F* (2, 73) = .42, *p* = .66), MR task (*F* (2, 73) = .82, *p* = .44), numeracy task *(F* (2, 73) = .44, *p* = .64) or RT *n*-back task (F (2,73) = 1.93, *p* = .15). With baseline equivalence shown, no adjustments were required of the pre-test scores and thus ANOVAs were selected for the change score analysis. However, there was a significant difference between conditions at baseline in the case of the TS *n*-Back (*F* (2, 73) = 3.77, *p* = .028). With baseline non-equivalence, further analysis using the selected change score analysis outlined in Chapter 5, is less reliable, and so a sensitivity analysis using the ANCOVA test with the T1 test scores as the covariate was applied to compare findings (Field, 2013) and is reported in the next section.

(c) *Training-related changes in pre- to-post-test performance scores*

To determine any differences from the pre- to post-performance scores (T1-T2), a change score analysis is conducted (See Chapter 5 for rationale) on each of the dependent variables for the three Conditions. First, the change score is calculated by subtracting the pre-test score from the post-test score for each participant on each dependent variable for the three conditions. Next, ANOVA tests are applied to the data with Condition as the independent variable, and time-point change scores on DSB, MR, Numeracy and RT *n*-Back task as dependent variables.

Results show a significant main effect of Condition for DSB F(2, 73) = 13.9, $p < .001$, $\eta_p^2 = .28$, indicated improved performance on the DSB task as a measure of WM capacity across Conditions, as shown in Table 22 below.

Table 22

Tests of between-subjects effects across Conditions on change scores for Digit Span Backwards (DSB) task

Dependent Variable: DSB Change

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	18.0[a]	2	9.02	13.9	.001	.28
Intercept	2.69	1	2.69	4.1	.045	.054
Condition	18.0	2	9.02	13.9	.001	.28
Error	47.4	73	.65			
Total	68.0	76				
Corrected Total	65.4	75				

a. R Squared = .28 (Adjusted R Squared = .26).

Bonferroni-corrected multiple comparisons were carried out and revealed significant differences in WM capacity between the computerised WM and Numeracy Conditions (p < .001) and between the WM and Control Conditions (p < .001). However, no significant difference was detected between the Numeracy and Control Conditions (p < .001) as reported in Table 23 below. This finding is confirmed in Table 17 and suggests the Numeracy Condition performed similarly to the Control Condition on the WM task.

Table 23

Bonferroni corrected multiple comparisons across Conditions on change scores for Digit Span Backwards (DSB) task

Dependent Variable: DSB Change

Bonferroni

(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
WM Cond	Numeracy Cond	1.03*	.22	.001	.48	1.58
	Control Cond	1.05*	.23	.001	.48	1.61
Numeracy Cond	WM Cond	-1.03*	.22	.001	-1.58	-.48
	Control Cond	.019	.23	1.00	-.54	.57
Control Cond	WM Cond	-1.05*	.23	.001	-1.61	-.48
	Numeracy Cond	-.019	.23	1.00	-.57	.54

Based on observed means.
The error term is Mean Square(Error) = .65
*. The mean difference is significant at the .05 level.

A significant main effect of Condition for MR $F(2, 73) = 31.6$, $p < .001$, $\eta_p^2 = .46$, indicated improved performance on the MR task as a measure of FR across the three Conditions, as shown in Table 24 below.

Table 24

Tests of between-subjects effects across Conditions on change scores for Matrix Reasoning (MR) task

Dependent Variable: MR Change

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	58.3[a]	2	29.2	31.6	.001	.46
Intercept	38.9	1	38.9	42.2	.001	.37
Condition	58.3	2	29.2	31.6	.001	.46
Error	67.3	73	.92			
Total	164	76				
Corrected Total	125	75				

a. R Squared = .46 (Adjusted R Squared = .45)

Bonferroni corrections tests of multiple comparisons were applied and revealed the significant differences in fluid reasoning as measured by the MR task, between the WM and Numeracy Conditions ($p < .001$) and the WM and Control Conditions ($p < .001$). Again, no significant difference was detected between the Numeracy and Control Conditions ($p = 1.00$) as recorded in Table 25 below, with both Conditions showing similar improvements in mean change score performance on the MR task (see Table 18).

Table 25

Bonferroni corrections tests of multiple comparisons across Conditions on change scores for Matrix Reasoning (MR) task

Dependent Variable: MR Change

Bonferroni

(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
WM Cond	Numeracy Cond	1.81*	.27	.001	1.16	2.47
	Control Cond	1.92*	.27	.001	1.25	2.59
Numeracy Cond	WM Cond	-1.81*	.27	.001	-2.47	-1.16
	Control Cond	.11	.27	1.00	-.55	.77
Control Cond	WM Cond	-1.92*	.27	.001	-2.59	-1.25
	Numeracy Cond	-.11	.27	1.00	-.77	.55

Based on observed means.

The error term is Mean Square(Error) = .92.

*. The mean difference is significant at the .05 level.

A significant main effect of Condition for Numeracy $F(2, 73) = 4.63$, $p = .013$, $\eta_p^2 = .11$, indicated improved performance on the standardised Numeracy task across the three Conditions, as shown in Table 26 below.

Table 26

Tests of between-subjects effects across Conditions on change scores for Numeracy task

Dependent Variable: Numeracy Change

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	77.1[a]	2	38.5	4.63	.013	.11
Intercept	.74	1	.74	.089	.77	.001
School	77.1	2	38.5	4.63	.01	.11
Error	608	73	8.32			
Total	686	76				
Corrected Total	685	75				

a. R Squared = .11 (Adjusted R Squared = .088)

Bonferroni corrections tests of multiple comparisons were applied and revealed significant difference in Numeracy performance between the WM and Control Conditions (p = .018). No significant differences were detected between the WM and Numeracy Conditions (p = 1.00) or the Numeracy and Control Conditions (p = .053), albeit the difference does not reach conventional significance levels (p > .05), as noted in Table 27 below.

Table 27

Bonferroni corrections tests of multiple comparisons across Conditions on change scores for Numeracy task

Dependent Variable: Numeracy Change

Bonferroni

(I) Conditions	(J) Conditions	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
WM Cond	Numeracy Cond	.37	.80	1.00	-1.59	2.33
	Control Cond	2.33*	.82	.018	.31	4.35
Numeracy Cond	WM Cond	-.37	.80	1.00	-2.33	1.59
	Control Cond	1.96	.81	.053	-.02	3.95
Control Cond	WM Cond	-2.33*	.82	.018	-4.35	-.31
	Numeracy Cond	-1.96	.81	.053	-3.95	.020

Based on observed means.
The error term is Mean Square(Error) = 8.32.
*. The mean difference is significant at the .05 level.

There was a non-significant (*ns*) main effect of Condition for changes in performance from T1-T2 for RT *n*-Back task $F(2, 73) = .51$, $p = .60$, $\eta_p^2 = .014$. The results indicate no significant change in response times on the *n*-Back task as a measure of FR for the three Conditions, as shown in Table 28 below. As no significant differences were revealed between Conditions, no further post-hoc tests were carried out.

Table 28

Tests of between-subjects effects across Conditions on change scores for Response Time (RT) *n*-Back task

Dependent Variable: Response Time (RT) *n*-Back Change

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9757[a]	2	4878	.51	.60	.014
Intercept	261	1	261	.03	.87	.000
Conditions	9757	2	4878	.51	.60	.014
Error	700801	73	9600			
Total	710760	76				
Corrected Total	710558	75				

a. R Squared = .014 (Adjusted R Squared = -.013)

As reported previously, a significant difference at T1 across the three Conditions was revealed for the TS *n*-Back task which make change score analysis using the ANOVA test less reliable (Knapp & Shafer, 2009). The ANOVA test showed a *ns* main effect of Condition for TS *n*-Back task $F(2, 73) = 2.32$, $p = .105$, $\eta_p^2 = .060$, which indicated no improved performance on TS n-Back across the three Conditions as shown in Table 29.

Table 29

Tests of between-subjects effects across Conditions on change scores for Total Scores (TS) *n*-Back task

Dependent Variable: Total Score (TS) *n*-Back Change

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	109[a]	2	54.8	2.32	.105	.060
Intercept	155	1	155	6.60	.012	.083
Conditions	110	2	54.758	2.32	.105	.060
Error	1717	73	23.52			
Total	1995	76				
Corrected Total	1827	75				

a. R Squared = .060 (Adjusted R Squared = .034)

A sensitivity analysis was applied using the ANCOVA test to compare findings using the pre-test scores as a covariate in the analysis, hence minimising any confounding variables (Fields, 2013; Knapp & Shafer, 2009). Consistent with Owen & Froman's (1998) recommendations on the cautious use of ANCOVA out-with RCT designs, the correlation between the pre-and post-test score are reported and shown in Table 30 below.

Table 30

Correlation matrix for pre- and post-test Total Scores (TS) *n*-Back task

		Pre-TS n-Back	Post-TS n-Back
Pre- TS n-Back	Pearson Correlation	1	.34**
	Sig. (2-tailed)		.003
	N	76	76
Post- TS n-Back	Pearson Correlation	.34**	1
	Sig. (2-tailed)	.003	
	N	76	76

**. Correlation is significant at the 0.01 level (2-tailed).

First, pre-and post-test TS performance on the *n*-Back task positively correlate with a Pearson correlation coefficient of r = 0.34, p = .003. Hence, there is a positive relationship between total scores at pre- and post-intervention on this task.

Results from the sensitivity analysis using the ANCOVA are consistent with the change score analysis and revealed *ns* main effect of Condition at post-test, F(2, 72) = .075, p = .93, η_p^2 = .002, which did not merit further post-hoc pairwise comparisons.

(d) Standardised effect sizes of training-related changes

Cohen's *d* standardised effect sizes were calculated from the change scores for the three Conditions showing significant main effects using Comprehensive Meta-Analysis V.3 software (Biostat Inc, 2014) and are displayed in the forest plot in Figure 14. Results indicate that relative to the Control Condition, observed change scores in the WM Condition achieved a Cohen's *d* of +.98 (95% CIs .39 to 1.58) for the DSB task; a Cohen's *d* of +1.34 (95% CIs .72 to 1.96) for the MR task, and a Cohen's *d* of +.65 (95% CIs .08 to 1.23) for the Numeracy task.

Next, relative to the Control Condition, observed change scores in the Numeracy Condition achieved a Cohen's *d* of +.04 (95% CIs -.51 to .58) for the DSB task, a Cohen's *d* of +.16 (95% CIs -.39 to .71) for the MR task, and a Cohen's *d* of +.56 (95% CIs .004 to 1.12) for the Numeracy Task.

Finally, comparing the change scores for the WM and Numeracy conditions, the WM Condition had larger Cohen's *d* for the DSB task of +1.08 (95% CIs -.36 to 0.73) and for the MR task a Cohen's *d* of +1.35 (95% CIs .75 to 1.95). However, there was no significant difference between these two Conditions for change score outcomes in the Numeracy task with Cohen's *d* of +.18 (95% CIs -.36 to .73).

Study name	Statistics for each study						
	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
WM_Cont Numeracy	0.653	0.293	0.086	0.078	1.228	2.227	0.026
WM_Cont DSB	0.985	0.303	0.092	0.392	1.578	3.256	0.001
WM_Cont MR	1.342	0.316	0.100	0.722	1.962	4.242	0.000
Num_Cont Numeracy	0.565	0.286	0.082	0.004	1.125	1.974	0.048
Num_Cont DSB	0.036	0.281	0.079	-0.514	0.586	0.130	0.897
Num_Cont MR	0.158	0.281	0.079	-0.393	0.709	0.562	0.574
WM_Num Numeracy	0.184	0.278	0.077	-0.361	0.729	0.662	0.508
WM_Num DSB	1.076	0.297	0.088	0.494	1.658	3.623	0.000
WM_Num MR	1.350	0.307	0.095	0.747	1.952	4.389	0.000
	0.667	0.098	0.010	0.475	0.858	6.831	0.000

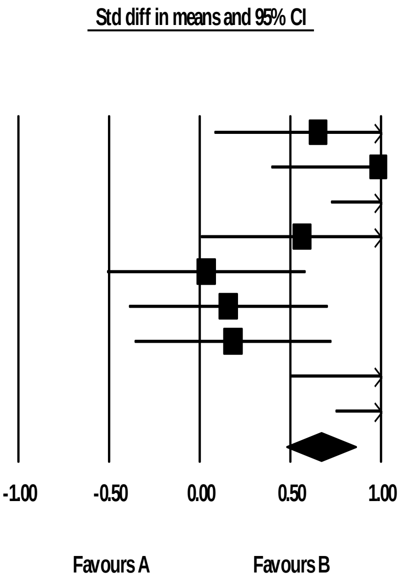

Figure 13: Meta-analysis and forest plot displaying standard effect sizes and confidence intervals for three Conditions

An effect size for each comparison of WM outcomes relative to control conditions is shown in the left-hand side of the forest plot in Figure 13. On the right-hand side, there is a graph which plots the standardised effect size for each of the measures and its associated 95% confidence interval. The black diamond at the bottom of the graph shows the mean effect size of the all the measures shown in the graph. If the confidence intervals do not cross 0, the effect size is statistically significant as confirmed by the z-value and p-values in the table. In this case, the average effect size for WM outcomes compared to all control conditions is .67, which is statistically significant ($p < .001$), medium effect size.

(e) Analysis of gender effects

Further analysis of possible effects of gender revealed no significant main effects for Gender across the three Conditions at T2 for any of the dependent variables (all *p* -values > 0.251).

6.3 SUMMARY OF RESULTS

6.3.1 Training-transfer effects for the computerised working memory condition

Results suggest that computerised WM training delivered statistically significant near-transfer effects to improve WM capacity as measured by DSB task (Cohen's *d* of + 0.98). Comparing Conditions on the DSB task, there is a decrease in performance scores for both the computerised Numeracy Condition and non-active Control Condition (mean score change difference = -1.96), which triangulates the significant effects reported for the WM Condition, suggesting the computerised WM training programme specifically privileges improvements in WM capacity.

Further, there was evidence also of a far-transfer effect from the computerised WM Condition to numeracy outcomes (Cohen's *d* of +.65 (95% CIs .08 to 1.23). The higher transfer effects reported in this study appear to suggest that the adaptive computerised WM training programme, which combines training tasks across verbal and visuospatial modalities, successfully activated shared substrates underlying WM, FR and numeracy performance (Titz & Karbach, 2014).

The WM training also resulted in transfer to FR (Cohen's *d* of +1.34 (95% CIs .72 to 1.96). The interpretation of whether this represents near- or far-transfer poses some interesting questions. Conway et al. (2003) define 'far-transfer' as transfer between tasks designed and held to theoretically and empirically measure different constructs (i.e. tasks of WM, FR and numeracy are all dissimilar). 'Near-transfer' in contrast, is understood as transfer between tasks designed and held to theoretically and empirically measure the same underlying processes and / or construct (i.e. measures of WM). Given these definitions, FR may be regarded as far-transfer, in respect of the WM training. However, there is an alternative interpretation taking into account possible 'task impurity' (Booth et al. 2010) of the MR task. Chuderski & Necka (2012) note a complex pattern of correlations between measures of WM and FR, which might in turn indicate that the results here reflect near-transfer from WM to FR. However, complications in interpretation of WM to FR transfer do not diminish the key finding of the study which is the far-transfer of the WM training to numeracy outcomes.

Results should also be interpreted within the context of implementation fidelity issues. As discussed in Chapters 1 and 4, implementation fidelity is a moderator of high transfer effects (Fixsen et al. 2005; Shipstead et al. 2013) and will be investigated in Study 3, reported in Chapter 8.

6.3.2 Training-transfer effects for the computerised numeracy condition

Preliminary inspection of mean scores changes from T1-T2 detailed in the descriptive statistics suggests that numeracy performance in both intervention conditions improved. Closer analysis of the results shows the computerised numeracy training programme marginally improved numeracy performance (p = .053), albeit this does not qualify as strong evidence of significant near-transfer effects to numeracy performance. As previously noted in Chapter 1 the impact of children's perceptions of numeracy are shown to influence numeracy performance. Indeed, receiving the computerised numeracy training programme may have improved children's perceptions of numeracy by boosting their motivation and engagement for numeracy, which may have been a contributing factor in the improved numeracy scores for this group. This is explored in Study 2 reported in the next chapter.

Results do not support evidence of far-transfer effects to tasks of WM or FR for the computerised numeracy training programme. With purported shared variance between numeracy and WM and between FR and WM (See Chapter 3), this is an unexpected finding. Perhaps these findings can be accounted for by the nature of the computerised numeracy training tasks themselves, since they may not have engaged components of WM or FR to a sufficiently challenging level, reputed to underpin far-transfer effects (Apter, 2012; Diamond, 2013). Another plausible explanation for the unexpected finding may be related to issues of implementation fidelity as a suppressor variable (Cook & Campbell, 1979), and this is considered further in Study 3 in Chapter 8.

6.3.3 The non-active Control Condition

The non-active Control Condition faired least well of all Conditions across all dependent variables from T1-T2. It is possible that this indicates measurement error from selection-maturation bias (Cook & Campbell, 1979). For example, the author highlighted in the previous chapter the interfering event (Robson, 2011) with a change in class teacher, which may account for the decrease in score performance at T2, and is considered further in Chapter 8. Another explanation indicated in the literature may be resentful demoralisation, resulting in pupils' reduced effort and engagement during testing. Such a phenomenon arises because Control Conditions usually wish to receive the intervention (Cook & Campbell, 1979). Conversely, the poor performance of the Control Condition may somewhat be magnified relative to the other conditions by the 'Hawthorne Effect'. For example, pupils receiving both training programmes may have expected to improve simply by receiving the intervention in addition to their regular curriculum instruction, thus improving their overall performance (Sternberg, 2008), or from simply having attention from their class teacher and/or author (McCarney et al. 2007). However, the Hawthorne Effect is unlikely to account for the magnitude of training-transfers effects reported in this study.

6.3.4 The n-Back task as a secondary outcome measure

The *n*-Back task was selected as a secondary outcome measure for the study for a dual purpose: (a) to provide another measure of FR by triangulating results with the

MR task (Raven 2000; Sternberg, 2008) and, (b) to add to the evidence base about its feasibility and acceptability for use with children.

Results for the *n*-Back task are inconsistent. There was a *ns* main effect across Conditions for the RT and RS *n*-Back task. Closer inspection of the mean scores appears to suggest that the WM Condition reduced RT by T2, which is consistent with their better performance on the MR task, both selected as measures of FR. Perhaps this consistency provides further evidence to support the claim made here, that Memory Quest Flex (Junior) successfully mediated shared substrates underlying WM, FR and numeracy performance (Titz & Karbach, 2014).

Inconsistent results are found for the Numeracy Condition, with increased RT on the n-Back task by T2, which may indicate the stimuli presentation decayed with increasing time lapsed, which is consistent with the construct of WM and FR as a limited-capacity process that operates on a trade-and-switch system (Hitch et al. 2001; Towse & Hitch, 1995). Results may also be accounted for by the variation of the *n*-Back task selected in this study, which used numerical digit sequences as the stimulus. Hence, perhaps the task accessed underpinning numeracy recognition processes, rather than measurement of improvements in FR (Morrison & Chein, 2011). Use of a visuospatial or letter recognition *n*-back task would circumvent the possible bias.

Disparity is observed between performances on both tasks of FR used for the Control Condition. The Control Condition observed improvement on mean score MR task performance from T1-T2, yet there was *ns* main effects on RT *n*-Back task.

Such inconsistent results likely reflect measurement error which are explored further in Chapter 9.

CHAPTER 7: RESULTS AND ANALYSIS

STUDY 2: DEVELOPMENT AND VALIDATION OF THE PUPILS' PERCEPTIONS OF NUMERACY QUESTIONNAIRE (PPNQ)

Study 2 rationale and aims, design and instrumentation were presented in Chapter 5

7.1 PROCEDURE

The 76 participants completed the PPNQ (Appendix D). Participants in the computerised WM training condition (*n*=25) and the computerised numeracy training condition (*n*=27) then took part in the 7-week computerised training programme comprising 4-5 weekly training sessions. Children in the control condition (*n*=24) also completed the PPNQ. At intervention follow-up, all pupils (*N*=76) were asked to complete the PPNQ again to provide comparison across the T1-T2 time-point.

7.2 RESULTS

This section presents the results for Study 2 and reports the following (a) structure and dimensionality of the pre-intervention scores on the PPNQ, (b) reliability checks on the PPNQ, (c) analysis of the post-intervention scores on the PPNQ, (d) comparison of factors scores and score changes from pre-to post-intervention.

(a) Structure and Dimensionality of pre-intervention scores on the PPNQ

PCA was carried out on the scores for the 6 items for each of the 73 participants at pre-intervention for whom data was available. Item 6 failed to meet the criteria of ≥ .50 in regard to the anti-image correlation as a measure of sampling adequacy (MSA) and was removed. Re-analysis of the remaining 5 items yielded a component solution accounting for 55.5% of the variance. However, low extraction communality (.334) was observed for Item 3, indicating low reliability, and the exploratory analysis was re-run with this item excluded. The final single component model based upon 4 items accounted for 63.3% of the total variance, and met minimum standards for sampling adequacy and factorability (KMO statistic .78) (Kaiser, 1974) and sphericity (Bartlett's Test χ^2 (6) = 89.6, p< 0.001). Final factor loading scores for the analysis are shown in Table 31 below.

Table 31

Component matrix for pre-intervention pupils' perceptions towards numeracy

Item	Component
1	.75
2	.84
4	.82
5	.78

Anderson-Rubin factor scores were generated (Field, 2013) for use in analyses below to provide a composite measure (with a mean of 0 and a standard deviation of 1), here a standardised z-score, for pupil attitude towards numeracy.

Reliability analysis revealed that four items of the PPNQ had good internal consistency reliability (Cronbach's α = .81) (Field, 2013).

(b) Analysis of post-intervention scores on the PPNQ

PCA was carried out on the scores for the 4 items previously identified above for each of the 70 participants at post-intervention. This yielded a single-component model accounting for 48.8% of the variance which met minimum standards for sampling adequacy and factorability (KMO statistic .68) (Kaiser, 1974) and sphericity (Bartlett's Test χ^2 (6) = 35.4, *p*<.001). Final factor loading scores for the analysis are shown in Table 32 below. Note, however, that the communality for Item 5 (.38) indicates somewhat low reliability. However, the communalities for the remaining three items were satisfactory and ranged from .45 to .59.

Table 32

Component matrix for post-intervention pupils' perceptions towards numeracy

Item	Component
1	.67
2	.73
4	.77
5	.62

Anderson-Rubin factor scores were derived (Field, 2013) and their descriptive statistics are shown in Table 33 below with maximum post-intervention factor scores of 3.46.

Table 33

Distribution of Anderson-Rubin factor scores from Pupils' Perceptions of Numeracy Questionnaire (PPNQ)

Time point	Mean	SD	Skewness (z-score)	Kurtosis (z-score)
Pre-intervention	.019	.99	0.55	-2.72
Post-intervention	.000	.96	6.90	6.67

A higher score on the PPNQ indicates more negative attributions towards numeracy. From the data in Table 33, the mean score from pre-to-post-test intervention indicates a more neutral or positive perception of numeracy. However, analysis of the distribution of factor scores using the z-scores of skewness and kurtosis (ranging from .55 to 6.90), indicates non-normality of between group comparisons. A sensitivity analysis using boot-strapped parametric univariate ANOVA test confirmed this finding $F(2,73) = 1.84$, $p = .17$.

(c) Comparison of T1 factor scores by condition

In the case of pre-intervention factor scores, there were no significant between-condition differences ($n = 76$, Kruskal-Wallis standardised test statistic 3.26, 2df, $p = .196$, two-tailed test).

However, there was a significant difference between conditions in the case of post-intervention factor scores (total $n = 76$, Kruskal-Wallis standardised test statistic 10.2, 2df, $p = .006$, two-tailed test). A sensitivity analysis using boot-strapped parametric univariate ANOVA test confirmed this finding $F(2,72) = 5.40$, $p = .007$. Further analysis using Mann-Whitney U Tests confirmed that the source of the difference was the higher scores in the case of the Control Condition compared to the joint intervention conditions, Mann-Whitney U standardised test statistic -2.98, $p = .003$, two-tailed test.

(d) T1-T2 changes by condition

T1-T2 in Anderson-Rubin factor scores across all three conditions were compared for all 76 participants using Kruskal-Wallis test (Kruskal-Wallis standardised test statistic 8.62, 2df, *p* = .013, two-tailed test. Then non-parametric Wilcoxon Paired Sample Tests were used to compare conditions and revealed no significant change in pupil perception of number following intervention in either the WM Condition (n = 25, standardised test statistic -1.58, p = .115, two-tailed test) or Numeracy Condition (n = 27, standardised test statistic -1.61, p = .107, two-tailed test). For the non-active Control Condition (n = 24, standardised test statistic 1.94, p = .052, two-tailed test), pupil perception of number did not significantly become more negative, but approached borderline significance.

7.3 SUMMARY OF RESULTS

Study 2 developed a reliable single construct scale to measure children's perceptions of numeracy (internal consistency Cronbach's α = .81). Findings of the PCA applied to the PPNQ identified a unidimensional factor structure with the four items providing an important response to foundational discussions on pupils' perceptions of numeracy in a Scottish context.

The higher the score on the PPNQ, the more negative attitude and perception of numeracy. Results indicate that by T2, higher scores were found in the Control Condition relative to the training conditions, albeit this did not reach conventional levels of significance (p = .052). This finding is cross-validated with the overall poorer performance of the Control Condition on all dependent variables relative to the other two intervention conditions reported in Study 1, in Chapter 6. The trajectory of the Control Condition is consistent with evidence that control conditions fair less well in real-world research (Cook & Campbell, 1979; Robson, 2011). Indeed, findings for the Control Condition may signal a more pressing concern. Poor outcomes for the Control Condition across all dependent variables in Study 1 is a growing concern and was followed up by the author with the class teacher to identify supports. Follow-up of concerns in research is important for research purposes, but more fundamentally, is a duty for accountable and ethical practice (Frederickson, 2002).

The literature identifies positive perceptions of numeracy a mediating variable in numeracy performance (Hasse et al. 2012). PPNQ findings for both intervention conditions prove a valuable source of information. For example, the PPNQ was sensitive enough to detect emergent positive perceptions of numeracy in both conditions, which illuminates the statistically significant improvements in numeracy scores for the WM Condition, and the improved scores of the Numeracy Condition which were close to conventional significance. Given that no significant changes in pupils' numeracy perceptions were detected by the PPNQ, results here may be consistent with studies that show negative perceptions of numeracy are particularly challenging to ameliorate (Dweck, 2008; Mazzocco & Kover, 2007). Issues of acceptability and feasibility of the computerised training programmes may offer alternative explanations to account for the non-significant findings of the PPNQ. Particularly, when Mueller & Dweck's (1998) posit that participants' beliefs about the effects, or impact of training do influence, and can even trump, test performance. These issues are discussed more fully in subsequent chapters.

Worthy of note is that children in both intervention groups reported improvements in understanding the class teacher during numeracy tasks, indicated by their shift in response to the PPNQ item: *"Some kids do not understand what the teacher says in number."* Perhaps access to computerised training programmes facilitate children's access to the numeracy curriculum (and improves numeracy performance) by supporting greater understanding of the class teacher and the language used during numeracy lessons. Specifically, opportunities for recall and consolidation of both verbal and visuospatial stimuli across different virtual contexts as afforded by the training programmes, may have a key role in supporting children to understand the language of numeracy (Raghubar et al. 2010). Review of the literature presented in Chapter 2 highlights the importance of understanding the language of numeracy for numeracy development.

Drawing generalisations from the findings of this study requires caution since a single method of data collection should not be considered in isolation, but complement the triangulation process (Boyle & Kelly, 2017; Woolfson, Whaling, Stewart & Monsen, 2003). Therefore, the next chapter now turns to the implementation audit, to both expand upon and rule out alternative causal explanations about the quantitative findings.

CHAPTER 8: RESULTS AND ANALYSIS

STUDY 3: PARTICIPANT EVALUATION OF TWO COMPUTERISED TRAINING PROGRAMMES

PART 1: PUPILS' EVALUATION OF COMPUTERISED TRAINING PROGRAMMES

The rationale and aims, design and instrumentation for Study 3, Parts 1 and 2 were presented in Chapter 5

8.1 METHODOLOGY

Further details can be found in Chapter 5. The focus group schedule is shown in Appendix E and transcripts for both training conditions are included in Appendix F.

8.2 PROCEDURE

The author is experienced working with children and running group discussions, so had the role of moderator in both focus groups. As moderator, the author encouraged participants to express their own and different viewpoints by reassuring each participant that there was no correct answer, but that everyone's contributions were valuable. Participants were offered the opportunity to talk to the author after the focus group if required, although no participant used this facility. To ensure maximum participation, the author used prompts where required (Littoselletti, 2003), such as: *Does anyone want to add something? Please can you tell me more about that?*" Data was recorded in handwritten notes by a colleague of the author who was blind to the study. During the transcription process prompts and any repetitions were not included to ensure clearer interpretation and analysis of responses (Kitzinger, 1994; Littoselletti, 2003). Transcripts from both focus groups are provided in Appendix F.

8.2.1 Data analysis strategy

Details of the selected analysis are described in Chapter 5. At least one illustrative quote from a participant for each sub-theme is selected and reported to facilitate understanding of the emergent theme labels. Information is then presented in thematic tables shown in Table 32 for the computerised WM training programme, and Table 33 for the computerised numeracy training programme. Interpretation of the results is guided by the eight components emphasised in the literature as important contributors to implementation fidelity (see Figure 3) (Durlak & DuPre, 2008).

8.3 RESULTS

The author analysed the data looking for data that was exclusive and / or illustrated a trend. Findings from the focus groups are represented by two theme levels comprising emergent themes and sub-themes. Thematic tables for the computerised WM training programme and computerised numeracy training programme are presented in Tables 34 and 35 respectively.

To minimise any biased inference from the author, all samples of qualitative data were checked by a colleague of the author who was blind to the study rationale. Percentage agreement is not reported as the author was simply looking for data that is exclusive and / or illustrative of a trend. Disagreements about the themes under which user statements were to be placed were resolved by discussion (Glaser & Strauss, 1967; Hammersley, 2007).

From the outset, it is important to note that a threat to validity may arise from the different levels of the intervention received (Cook & Campbell, 1979). For example, the WM Condition completed all 28 training sessions and the Numeracy Condition completed 23 training sessions.

Table 34

Emergent themes from the WM condition focus group

	Themes	Sub-Themes	User statement - ID Code/Gender
Utility to school work	Improvements in memory	Visual memory	***10/F***- *I remember more, like I can remember more of what is written on the board. When the teacher rubs it off the board too fast, I just remember it now. I can understand her more now.*
		Auditory memory	***-2/F*** *-It helped me remember what the teacher said or wrote on the board. I can work on my own more.*
	Improvements in other higher-order executive functions	Periods of sustained attention and listening	**7/M-** I am better at listening.
		Comprehension	***7/M***- *I remember what the teacher has told me more and think the memory games have helped me to remember lots of things she says and I understand stuff she says I remember it a bit better. I don't get so worried about doing stuff in class.*
		Self-correction	***6/M***- *Playing the games on the computer has helped me remember to check my jotter. It has helped all my writing but story writing is better because I remember to go back and check my full stops. I also remember now to use finger spaces. I have had Star Writer award. I'm not so worried now.*
		Multi-tasking-holding tasks in mind	***3/F*** *The game helped me think about more things at the same time*
	Curriculum-based outcomes	Retention and manipulation of multiplication tables	***3/F***- *The programme helped me remember timetables because I used to always forget them. I remember my numbers faster when I'm doing my sums.*
		Accurate spelling	***10/F***- *I'm a better speller now after the programme because I am more careful of getting words wrong. The memory games have helped me to think of what the word looks like. I can then use my spelling strategies to write it.*
		General task performance	***7/M***- *I am not making mistakes with my work. I do it right first time now.*
		Faster completion	***6/M***- *The memory games helped me write more because I can get my answers faster in my head.*
	No benefits reported		**1M**- Not really...it didn't help me with anything.

	Themes	Sub-Themes	User statement - ID Code/Gender
Attitudes to learning	Motivation	Settled to learn	**-2/F-** My Mum says my homework is better because I don't take so long to do it now. I think I know what I have to do now and do it more on my own. I don't get so upset with my homework. I give it a try. ***7/M-*** *Memory games were fun and helped me to stop fidgeting. I can sit longer now and feel calmer in my seat. I don't have to get up as much. I can listen better now.*
Programme features	Training programme environment	Scaffolding for usability	3/F- I had to concentrate and look hard at all the different games and colours. Sometimes they were moving pictures and sometimes I had to listen to the different music to remember the different music. 1/M- Following the treasure map was fun and easy… it did stop me rushing ahead everyone. The games were good because they were like things we get asked to do, like remember noises or when we are sent a message.
		Social presence	6/M- I liked having my avatar – it helped me get to the treasure chest and showed me where I was around the treasure map each day.
	Feedback process	Music and sound effects	6/M- I liked the music and sounds in the different games and after each answer because I would know if I got it right or got a reward. It helped me to keep going round the treasure map. 10/F- We work through the treasure map every day to play the memory games. I had a lot of rewards and ticked my log book after I finished so I could get a certificate and class rewards.
		Varied reward system	
		Entertaining characters	**6/M** -Play the memory games with all the funny games and little avatars. There were lots to look at with all the bright colours, it was great!
		Practical games	**1/M-** The games were good because they were like things we get asked to do, like remember noises or when we are sent a message.
		Routine supports improved	**1/M** It was good having the games every day and in small groups. I got to the end of the games after few weeks I got faster.

		performance	
		No benefit reported	
	Collaboration	Regular and small group sessions	**1/M** It wasn't as noisy as class. **10/F**- It was good because we did it every day and I got better. I can do it so fast on my own now. It was great doing it every day.
Implementation	Deployment	Integration with school curriculum	***3/F****-It would be good to use in class when we do maths and spelling. Can the whole school use Memory Quest? It really helped.*
	Logistics	Technical problems	**1/M-** It was annoying and wasn't fair when my computer didn't work and I had to change to another one when everyone else's was ok. **10/F** – Sometimes the pictures were hidden and I couldn't see them but had to click on the screen where I thought they would be.
	Logbooks	Challenge	***7/M*** *challenge to keep getting better*

Table 35

Emergent themes from the numeracy condition focus group

	Themes	Sub-Themes	User statement - ID Code/Gender
Utility to school work	Multi-tasking – holding tasks in mind	Fluency and capacity	***36/M*** *– I am faster at working out different things in my head and getting an answer because Destination Maths had a game with a big clock and we had to beat different avatars.*
	Improved numeracy performance	Accuracy with numbers	**36/M-** I can count better making fewer mistakes. My sums are neater in my jotter because i am not rubbing out so much.
		Faster completion of number tasks	***44/F*** *– The programme made my brain work and i can do more in maths and in language now. I can think faster*
		Skills using learning aids	***44/F*** *– I can think about more stuff and not get muddled up so now I can think of answers and use my number square to find the answer.*
		Comprehension of maths vocabulary	***24/F*** *– It helped me to understand the teacher, like when we do bigger and smaller, I get that now.*
	No benefit reported		***631M-*** *I don't think my school work is different. It's just the same*
Attitudes to learning	Confidence with numeracy Value of practice	Practice improves efficiency; accuracy; speed	**44/F-** *The games were good because we went a lot and so I got to practice and work on my own and try things out… It helped because I worked on my own on the computer games.*

Table 35 continued

	Themes	Sub-Themes	User statement - ID Code/Gender
Programme features	Training programme environment	Limited scaffolding for usability	**45/M, 31/M** – *Sometimes I couldn't remember what games I had tried and forgot the ones I had done an sometimes went back to the same game the next day.*
			24/F – *We were all playing different games and you could pick any game – some boys just picked the difficult games straight away and they were too hard for them anyway.*
			26/M, 31/M – *I didn't like the games against the avatars because they were timed games and I never beat them. They always won.*
		Positive social presence	**44/M** –*When I finished I could use up the points to buy a reward for my avatar… She was a lucky avatar*
	Negative feedback process for learning		
		Negative sounds with errors	**27/M** - *I got a bit upset and didn't like getting the answers wrong* **31/M** - *… when it made a loud sound and took away points*.
		Loss of earned reward points with errors	
	Motivators	Characters	**44/F** – *The maths games were good because I got to pick which one I played and it spoke to you to tell you what to do and if you got stuck it sometimes helped you.* **44/F** – *I loved my avatar and got to buy clothes for her with the reward points.*
		Reward points	
		Weekly class rewards	**31/M** – *I liked when the teacher gave us rewards every week in the class because we had tried hard with the computer games. That was fun and she was proud of us.*
		No benefit reported	**45/M** – *Don't know, it was a bit boring and too hard to find the games.*
Implementation	Collaboration	Small group	***27/F***- *Having time in small groups was good, it was quieter to help me try hard, but.*
	Logistics	Review session length	**36/M**- *I could choose different maths games every day and then there was time at the end for rewards* **31/M** – *The games were fun but sometimes I wish I had more time to play the reward games.*
		Technical challenges	**45/M** – *One time I shared a computer because my computer wouldn't work. I got fed up and it not working made me think the programme wasn't so good really. The next time the computer never worked so I used an iPad to play the maths games. It was better and faster.*
	Logbooks	Challenge	***31/M*** - *I think the logbook was ok, it helped me keep up with everyone and I knew how I was doing, it felt good.*

8.3.1 Pupils' perceived impact of the computerised training programmes

Themes from the focus group with the WM Condition appear to reflect pupils' practical understanding of the importance of WM and its involvement in wider curriculum performance. Evidence from the Numeracy Condition suggests pupils understand the aims of the programme to improve numeracy, but do not demonstrate awareness of any potential wider benefits. Perceived impact of the training programmes emerges from both focus groups, albeit qualitatively different. For example, pupils in the WM Condition report a wider range of benefits that include near-transfer effects across different memory modalities and other higher-order executive functions. Far-transfer effects are also reported in respect to specific numeracy skills, such as recall of number facts with improved fluency, and for literacy, improved spelling. Interestingly, reported benefits to numeracy performance evidenced in the focus groups for both conditions, are not as clearly detected by the PPNQ, and suggests social desirability bias in focus group responses.

However, perhaps the positive themes generated from the focus group for both intervention conditions reflect positive perceptions of learning, generally, with pupils remarking greater confidence to "*have a go*" and to work with greater independence. Emergent themes suggest that both computerised training programmes offered valuable opportunities for pupils to practice skills and help peers. More specifically, both focus groups report developments in understanding numeracy language used by the class teachers, which is consistent with emergent positive ratings on this item in the PPNQ (see Chapter 7).

8.3.2 Characteristics of the computerised training programmes

Key features of the virtual computerised training environment emerge as primary themes for acceptable computerised training programmes in line with Connolly et al.'s (2009) evaluation framework for games-based learning (see Chapter 4). For example, pupils remarked on developing emotional connections with programme avatars and characters, and perceived value of the coaches as aides to learning, alongside the feedback and reward systems of both programmes. Scaffolding mechanisms of each programme are highlighted by pupils as a key feature for acceptability. For example, pupils in the WM condition commented positively on the attractive user interface of Memory Quest Flex (Junior), which they report provided clear structures of progression and diverse motivational feedback for learning. Conversely, Study Ladder was not as acceptable to the Numeracy Condition, citing a confusing user interface and minimal structure to guide task selection. Indeed, findings from the WM Condition reflect the quality of the programme with pupils requesting to extend its reach to the whole school.

8.3.3 Implementation issues of the computerised training programmes

Before moving forward, it is important to note differences in dosage between the conditions from the outset i.e. the WM Condition completed all training session, while the Numeracy Condition completed 82% of training sessions.

Implementation fidelity of computerised training programmes is a key moderator of their effectiveness (Melby-Lervag et al. 2013). Primary themes from the focus groups concerned the impact of enduring technology failures for both conditions, but particularly for the Numeracy Condition, which affected the duration of a number of training sessions. It is reasonable to suggest that ubiquitous technology problems and the unpredictability this brings to the training routine (i.e. dosage, duration and spacing of sessions across the time-point) may have influenced the negative perceptions of numeracy reported in the PPNQ. Perhaps then, ratings on the PPNQ for the Numeracy Condition may reflect their ambivalence towards the training programme, over say, their perceptions of numeracy specifically.

Pupils in both conditions reported training sessions as either too short, or too long. However, brief contact may be more functional and palatable to younger pupils. Intervention programmes that threaten to disrupt school routines may not win access to school or staff in the first place (Inchley, Muldoon, Currie, 2007).

Positively, primary themes for both groups reflect enjoyment of small group settings to complete the computerised training. Further, the pupil logbooks emerge as a key motivational tool for pupils. Albeit, analysis of the logbooks by the author indicated that 2% of the logbooks were not fully completed by the Numeracy Condition, and pupils reflected they were sometimes forgotten at the end of sessions. Adaptation to a class reward system rather than individualised rewards had positive outcomes, with most pupils in both focus groups acknowledging enjoyment of class rewards. On reflection, perhaps a formative pupil rating in the logbooks following each training session would helpfully identify children that might benefit from more individualised incentives.

It is important to interpret these findings within a broader context of implementation that is the focus of Part 2 below, and discussed more fully in Chapter 9.

PART 2: CLASS TEACHERS' EVALUATION OF COMPUTERISED TRAINING PROGRAMMES

8.4 PROCEDURE

During the half-day coaching session delivered by the author, both class teachers were asked to maintain training schedules at the end of every session for the duration of the 7-week implementation phase. Class teachers were asked to complete impact questionnaires independently at post-intervention follow-up. Completed training schedules and impact questionnaires are shown in Appendix H and I respectively.

8.4.1 Data analysis strategy

Further details can be found in Chapter 5. To aid the reader make sense of the messages of class teachers' entries in the training schedules, only distinctive information or information that extended themes gathered from the pupil focus groups is included for analysis. Additionally, for clarity of reporting only qualitative information from the impact questionnaires is reported in the analysis.

8.5 RESULTS

A summary of important process variables for both computerised training programmes is extracted from the completed training schedules using thematic analysis to understand the components of effective implementation in schools, and is shown in Table 36 below.

Table 36

Process variables for computerised training programmes extracted from training schedules

Process Variables	**WM Condition**	**Numeracy Condition**
Sessions completed (Total =28)	28	23 (+1 extra computerised training day delivered)
Deviation time from standard duration per session (mins)	15	45 (across 3 sessions)
Spacing • Daily • Typical 3-day spacing (one day + weekend) • Bank holiday = 4-day gap	 ✓ ✓ ✓	 4 days missed mid-week ✓ ✓

Themes emerging from class teacher training schedules are presented in Table 37.

Table 37

Emergent themes from class teachers' training schedules

	Theme	Computerised WM training programme	Computerised numeracy training programme
Pupils	Utility to school work	• Confidence with technology • Improved spelling • Recall of instructions • Numeracy- sums • Greater independence with general tasks	• Progress in numeracy • Greater independence with general tasks
	Motivation	• Highly motivated	• Mainly motivated • IT skills and technology problems reduced motivation
	Engagement	• High engagement- competitiveness • Sense of immersion • Some distraction • Useful for other classes across school	• Adequate engagement • Participation problems for some pupils e.g. interface too complex to select games, lack of structure, mismatched difficulty levels & negative reinforcements
	Attitudes to learning	• Growing independence • Keen to progress in general domains	• Growing independence • Keen to progress with numeracy
Class Teacher	Motivation	• Understood programme aims and role of WM in learning • Commitment to improve WM • Gradual independent facilitation of sessions	• Partially understood programme aims i.e. focus on numeracy • Some commitment to training • Gradual independent facilitation of session not possible • Prompted to complete training schedule
	Perceptions of the programme	• Clarity of instructions and intuitive interface • Games promoted progression and engagement • Motivating graphics and character	• Interface offered too much choice • Inadequate levels of scaffolding

Class Teacher	**Theme**	**Computerised WM training programme**	**Computerised numeracy training programme**
Implementation	Technology	• Missing graphics in some games • Occasional internet failure	• Limited computers • Sound problems • Occasional internet failure
	Dosage	• Regular and adequate sessions	• Variable
	Treatment fidelity	• Logbook adhered to mainly • Adherence to session programme	• Difficulties incorporating logbook into sessions • Significant co-ordination of resources to adhere to session programme
	Logistics	• 1 adult required to facilitate groupings	• 2 adults required to facilitate grouping • Ongoing adult role to support pupils navigate interface

A summary of distinctive qualitative information derived from thematic analysis applied to the class teacher impact questionnaires is provided in Table 38.

Table 38

Additional points extracted from class teacher impact questionnaires

	Computerised WM training programme	**Computerised numeracy training programme**
Dosage and intensity	• Regular small group delivery	• Compromised by difficulties organising and managing groups • Technology access and faults compromised intensity
Fidelity	• Model of gradual coaching and facilitation until class teacher independently facilitated • Weekly reward programme	• Continuous model of coaching and facilitation for class teacher by author • Weekly reward programme
Practical learning experience	• Games were practical and related to previous familiar contexts	• Games were practical and related to previous familiar contexts
Transfer effects	• Near- and far-transfer effects to literacy, numeracy, science and expressive arts curriculum and general skills required in classroom	• Mainly near-transfer effects
Sustainability	• Utility for whole school curriculum programmes • Integration with daily curriculum • Exploring multi-sensory approaches to support pupils' WM capacity.	• Integration of ICT with daily curriculum programmes and homework tasks

8.5.1 Staff perceived impact and characteristics of the computerised training programmes

Findings from the class teacher training schedules and impact questionnaires are consistent with emergent themes identified from pupil focus groups. Converging evidence is provided by a number of primary themes that include:

- observed improvements in literacy and numeracy skills in class

- developments in pupil independence and confidence in themselves as learners
- training routines that deliver consistent levels of dosage and consistent spacing of sessions across the total training phase support pupil progress
- value of coaching and support
- technology and organisational issues moderate training experiences of participants.

Consistent with pupils' views, features of the user interface and reward mechanisms noted by staff included:

- structure of the user interface and levels of scaffolding support enduring positive virtual experiences
- reinforcements and rewards influence early engagement levels.

8.5.2 Feasibility of the computerised training programmes for staff

Factors important for intervention readiness (Kelly & Perkins, 2012) emerged from the class teacher in the Numeracy condition. For example, the intervention highlighted concerns about some pupils' limited pre-foundational technology skills in the Numeracy Condition, which the class teacher was not fully aware before the intervention. Limited technology skills may have compromised pupils' access to the programme, which in turn, may account for some pupils in the Numeracy Condition who reported in the focus group, ambivalence towards the programme, and thus negatively influenced their engagement levels (Cuttance, 1998; Haase et al. 2012). Similar reflections from the class teacher in the training schedule may contribute in part, to the implementation challenges noted for the Numeracy Condition.

Further, the role of teacher as coach had a significant impact on the implementation process for both interventions. In the Numeracy Condition, two adults were required to facilitate pupil groupings. The teacher reported that difficulties organising and managing the additional third group meant routines were more difficult to embed. Training schedules provided fuller evidence of the impact of this, with inconsistent dosage and spacing of sessions relative to the WM Condition. However, progress with routines are reflected mid-way through the training schedules, which suggests three groups are manageable, although not desirable, when working within timetabling constraints to access a computer suite.

8.6 SUMMARY OF RESULTS

In real-world research, participant experiences illuminate evidence that is relevant (Dunsmuir & Kratochwill, 2013) and triangulation of the evidence provided by staff and pupils in this study indicated that the computerised WM training programme was most feasible and acceptable for use in primary schools. Indeed, expressions of interest arise for its use as a whole school curriculum programme. Synthesis of the evidence gathered from staff training schedules and impact questionnaires is consistent, but also extends evidence from the pupil focus groups, to identify four candidate moderators for acceptability and feasibility of computerised training programmes in schools which include: (a) virtual environment that provides clear scaffolding levels and motivation for engagement, (b) consistent dosage of training sessions, (b) consistent spacing of sessions, and (c) specific organisational drivers concerning resourcing. Organisational drivers, including organisational constraints and technology problems is a primary theme for staff and pupils, providing strong evidence to more fully account for the limited gains of the Numeracy Condition reported in Study 1 and 2.

The final chapter turns to the discussion of the findings for the three studies, reflecting on future directions and implications for educational psychologists in practice.

CHAPTER 9: DISCUSSION

9.1 REFLECTIONS ON STUDY OUTCOMES

The two main aims of this thesis were to:

- evaluate the effectiveness of two computerised training programmes in developing working memory and numeracy skills in primary school-aged pupils
- determine the acceptability and feasibility of those computerised training programmes to participants.

Before presenting the discussion, the main outcomes are summarised in Table 39.

Table 39

Summary of positive and negative study outcomes by condition

<u>Outcomes</u>	**<u>Computerised WM training</u>** **Memory Quest Flex (Junior)**	**<u>Computerised Numeracy Training</u>** **Study Ladder**	**<u>Control Condition</u>** **Regular curriculum**
<u>Positive</u>	• Statistically significant near-transfer effects to improve mean WM scores • Statistically significant far-transfer effects to improved mean FR and numeracy scores • Improved response time on *n*-Back task as secondary measure of FR • Staff & pupil experience of programme and implementation process • Impact of intervention on pupils and staff • Emergent positive perceptions of numeracy	• Emergent positive perceptions of numeracy	• Improved response time on *n*-Back task as secondary measure of FR
<u>Negative</u>		• Staff & pupil experience of programme and implementation process	• Deteriorating negative perceptions of numeracy

The results of Study 1 show that the adaptive computerised WM training programme, Memory Quest Flex (Junior) yields both near-transfer effects to WM, and far-transfer effects to FR and numeracy performance. Transfer-training effects were found at 3-week post-intervention follow-up and support claims of sustainable improvements over a medium timeframe (Melby-Lervag et al. 2013; Shipstead et al. 2010). These results support evidence that WM is malleable (Diamond, 2013; Klingberg, 2010) and that the WM training programme improves domain-general attentional resources which underpin both WM and numeracy attainment in primary school-aged pupils (Bergman Nutley et al. 2014; Dahlin, 2013; Holmes & Gathercole, 2014). The claims made about Memory Quest Flex (Junior) in this study are supported by large effect sizes. Indeed, relative to the Control Condition, the programme delivered near-transfer effects to WM capacity with a Cohen's *d* of +.98, and yielded far-transfer effects to FR with a Cohen's *d* of +1.34, and also to numeracy performance on a standardised numeracy assessment with a Cohen's *d* of +.65. These outcome values are consistent with the reported Cohen's *d* following CWMT. Indeed, Green et al. (2012) report near-transfer effects to WM capacity with $d = 1.3$, and Chacko et al. (2013) report $d = 1.7$. The SES reported for far-transfer effects to numeracy in this study are consistent with $d = .69$ reported by Dahlin (2013) following CWMT.

To provide robust quantitative data (Shipstead et al. 2010), this research design allowed comparisons of Memory Quest Flex (Junior) with both a Numeracy Condition, as active control condition, and a non-active Control Condition, to control for the Hawthorne Effect. Relative to both control conditions, evidence here suggests that the computerised WM training programme privileges significant improvements in WM capacity, FR and numeracy. Further, findings and large effect sizes cannot be fully accounted for by Hawthorne Effects.

9.1.1 Characteristics of multi-domain computerised training programmes

Another plausible explanation for the near- and far- transfer effects comes from analysis of computerised training programmes themselves. Cross-modality training tasks are reported to yield more robust near- and far-transfer effects than unimodal tasks, since the former summon shared processes that underpin WM, FR and numeracy, as discussed in Chapters 2 and 3 (Ferrer & McArdle, 2004; Owen et al. 2005; Titz & Karbach, 2014). This provides a plausible explanation for the benefits yielded by Memory Quest Flex (Junior), since it combines training across verbal and visuospatial domains of WM (Truedsson & Strohmayer, 2010).

A fundamental component of numeracy development is the interplay between procedural skills, which involve spatial WM, and conceptual understanding, that relies on verbal WM (Laski, Casey, Yu, Dulaney, Heyman & Dearing, 2013). Again, the cross-modality training tasks of Memory Quest Flex (Junior), relative to the numeracy training programme, Study Ladder, may have provided both procedural and conceptual learning experiences to a sufficiently challenging threshold to account for the far-transfer effects to improve numeracy performance. However, numeracy gains made by the Numeracy Condition, whilst not to conventional levels of significance (p = .053), should not be discounted since they may suggest that Study Ladder potentially may offer a source of enrichment to the numeracy curriculum. Albeit, further direct comparisons with another non-active control condition would be required since there are several issues with the control condition for this study, which will be expanded later in the chapter.

Another observation of multi-domain computerised training programmes is the role of motivation as a powerful moderator of effective training-transfer effects (Connolly et al. 2009; Moller & Hanson, 2016; Szatkowska, Bogorodzki, Wolak, Marchewka & Szeszokski, 2008). Training studies hold that high levels of motivation are required to activate components of the WM system located in the prefrontal cortex (Jaeggi et al. 2011; Krawczyk & D'Esposito, 2013). The implementation audit of this study captured pupil and staff experiences which were consistent with the research literature, and indicates that the highly motivating interface of Memory Quest Flex (Junior) may partially account for the sustained training-transfer effects evident at three-weeks' post intervention follow-up. An attractive, simple and structured user interface; combined with the embedded narrative of the treasure map were dominant themes for pupils and staff that make the programme very acceptable for use in the primary school context. These features are consistent with the framework for effective serious games proposed by Moller & Hansen (2016) (see Chapter 4).

9.1.2 Pupils' perceptions of numeracy

The PPNQ was developed and validated for use with primary-school aged pupils in this study and proved a helpful source of information about pupils' experiences of numeracy. Emergent positive pupil perceptions of numeracy detected by the PPNQ, combined with gains in numeracy scores for both intervention conditions are consistent with the research literature that identifies the causal interplay between numeracy perception and performance (Krinzinger et al. 2009). For pupils receiving the training interventions, a facilitating factor of more positive pupils' perceptions of numeracy identified by this study is greater understanding of the language of numeracy used in numeracy lessons. Further evidence of the validity of the PPNQ is found in the deteriorating perceptions of numeracy for the Control Condition which is also consistent with numeracy performance at T2. Taking these points into consideration, perhaps the PPNQ is sufficiently sensitive to detect neutral or negative perceptions of numeracy in a specific cohort of children that struggle with numeracy.

The PPNQ may be helpful to educators as part of the assessment process to identify those pupils who may benefit from numeracy interventions or learning supports (Rivera, Reiss, Eckert & Menon, 2005).

9.1.3 Challenges with control conditions

From a professional standpoint, it is important to note that the poor performance of the Control Condition in this study was a source of concern to the author. However, in light of research evidence, is not surprising since control conditions oftentimes fair least well of all conditions for two reasons: (a) participants do not receive the enrichment of the intervention, and (b), they are vulnerable to the risk of no treatment, whereby any gaps in skills / knowledge are usually cumulative (Prochaska et al. 2004).

In Chapter 5, the value of selecting a control condition in quasi-experimental research designs was considered as a source of comparison and precision for interpreting findings since the control condition helps to minimise threats to validity (Cook & Campbell, 1979). Melby-Lervag et al. (2013) hold that claims of near- and far-training transfer effects should be interpreted through scrutiny of the control condition. These researchers point to limitations across training studies concerning the comparison of WM training conditions with inadequate control conditions that do not sufficiently rule out the Hawthorne Effect. Hence these researchers called for more studies to utilise an active control condition. A noted strength of this study is that it incorporated both active and non-active control conditions to minimise threats to validity and reliability (Cook & Campbell, 1979). Results here indicate that the magnitude of near- and far-transfer effects observed in the WM Condition could not be fully accounted for by the Hawthorne Effect. However, two main characteristics of both control conditions in this study posed problems, which made drawing valid conclusions more difficult. These included:

- issues with the randomisation process
- extraneous suppressor variables relating to selection maturation bias.

The first point above concerns issues with randomisation and is considered further under the section on study limitations towards the end of this chapter. The second issue is considered now since the poor performance of the Control Condition on WM and numeracy tests cannot be explained by floor or ceiling effects as a source of measurement error. A more plausible explanation is that it was not possible to control extraneous suppressor variables (Cook & Campbell, 1979) that arose for the Control Condition, who experienced an interfering event during this study when there was a change in their class teacher. It is reasonable to suggest that with a temporary teacher, the Control Condition experienced different classroom routines, shifting expectations and predictability levels, which oftentimes create stress and negatively influence children's motivation and subsequent test performance (Carr & Dweck, 2011; Dishion & McMahon, 1998; Emmer, Everston & Anderson, 1980; Evans, Gonnella, Marcynyszyn, Gentile & Salpekar, 2005). Indeed, Duckworth, Quinn & Tsukayama (2012) found in a study of 508 children that their performance on subtests of the WISC-R improved when greater motivation levels were reported. Further still, numeracy performance and perceptions of performance are particularly vulnerable to anxiety (Passolunghi, 2011) and Diamond (2013) also cautions that EFs are vulnerable to stress.

Another extraneous variable that may partially account for training-transfer effects, especially improvements in numeracy scores, relates to participant maturation. Perhaps pupils' developing numeracy performance can be explained by ongoing access to the numeracy curriculum throughout the intervention. This hypothesis could have been cross-validated if the author had gathered numeracy performance data from class teacher judgements, which of course would add an additional source of reporting bias.

On reflection, interpretation of the findings highlights that computerised WM training programme privileges improvements to children's EFs and numeracy performance. More broadly, comparison between all three conditions, whilst taking into account problems arising from quasi-experimental research designs and suppressor variables, suggests that having access to a computerised training programme provides a source of enrichment to the numeracy curriculum for the targeted age group of pupils in this study. Implications for future directions are suggested later in this chapter.

9.1.4 Characteristics of the *n*-Back task

Inconsistent results of the *n*-Back task in this study raise interesting research questions for its use with younger children. The implementation audit identified that some children found the task challenging and for others the administration monotonous, which was exacerbated by returning to the task again for T2 data collection. By T2, children appear to have been making response choices either too quickly, or too late; plausible markers that levels of engagement may have reduced. Indeed, longer response times increase opportunities for decay of the number sequences from memory stores (Hutten & Towse, 2001). The sensitivity analysis provided strong evidence of the *ns* main effects on TS *n*-Back and may indicate measurement error issues which will now be considered.

The complexity of the *2*-back task used in this study may have disadvantaged some pupils. The *2*-back task has been demonstrated to place greater demands on EFs, over say the *1*-back task (Lendínez et al. 2015). When children aged 11 years old have been given the *1*-back task, which is not as challenging, they have performed reasonably well (Best & Miller, 2010). With *2*-back tasks, some studies note improvements in performance in children older than 11 years old (Gathercole, 1998; Huizinga, Dolan & Van der Molan, 2006). Since the task requires greater levels of inhibitory control, which is an EF known to develop with maturation, results suggest the task may have placed too great a demand on the inhibitory control abilities of children in this study, who were aged 7-8 years old. Consequently, perhaps this study has added to the evidence-base to determine that a typical sample population of children 7-8years old are unable to deal with the *2*-back task. Schleepen & Jonkman (2009) report that developmental differences in *n*-Back task performance (both the *1*- and *2*- back tasks), are specifically correlated with improvements in inhibitory control as measured by the Flankers task (Eriksen, 1995). Perhaps a supplementary measure of inhibitory control, such as the Flankers task, would have been a helpful additive task when administering the *2*-back task with this cohort of children as it would validate the performance on the *n*-Back task as a measure of FR, and might helpfully determine the variance between FR and inhibitory control. On reflection, some pupils found the task laborious, which in light of the evidence above may reflect their difficulty with the task. Together, waning motivation levels and/or rising stress levels, would ultimately impair cognitive flexibility and inhibitory control functions (Diamond, 2013), and impair test performance (Duckworth et al. 2012; Oaten & Cheng 2005).

The literature identifies the *n*-Back task as an established measure of WM and FR with adults and children (Diamond, 2013; Melby-Lervag et al. 2013). However, this study has made several key points about features of study design, characteristics of the task, variations in the task with children and other implementation issues. First, study designs that only use non-active Control conditions do not sufficiently control for the influence of Hawthorne Effects (Jaeggi et al. 2008; Jaeggi, Buschkuehil, Jonides & Shah, 2011). However, *ns* findings in this study, when both active and non-active control conditions are utilised suggest findings are not accounted for by the Hawthorne Effect. Rather, characteristics of the *n*-Back have a key role in the outcomes of this study. The *2*-back task used in this study appeared more complex than children aged 7-8 years could manage. Where the *n*-Back task may be too complex, the literature suggests interpretation should be complimented by supplementary tasks measuring inhibitory control, such as the Flankers task (Schleepen & Jonkman, 2009). Next, the use of a standard implementation protocol for administration of the *n*-Back task with children would facilitate consistency across studies, but should also recognise the possible facilitating role of the key adult facilitating the task with younger children.

Findings indicate *ns* main effects for the *n*-Back task across Conditions over the time point. The design of this study which used active and non-active control conditions has avoided some of the methodological issues observed in the literature when only non-active control conditions are used with the *n*-Back task (Jaeggi et al. 2008). Instead, the *ns* main effects for the *n*-Back task may be more fully understood by the task characteristics with this age group, and thus accounted for by measurement error (Fredricks, Blumfeld & Paris, 2004; Reeve, 2006). Therefore, conclusions here suggest that the *n*-Back task was not a valid tool as a measure of FR with 7-8 years old primary school-aged pupils.

9.2 IMPLEMENTATION FIDELITY OF COMPUTERISED TRAINING PROGRAMMES

Implementation science holds that the quality of implementation can trump the effects of interventions (Durlak & DuPre, 2008). Findings of this study are now considered within the broader context of implementation fidelity (See Chapter 1 for details) as advised by more recent research studies and meta-analyses studies of computerised training programmes (Alloway et al. 2013; Melby-Lervag et al. 2013; Schwaighofer et al. 2015). It is worthy of note that Study 3 gathered feasibility and acceptability data from pupils and teachers to understand the training transfer-effects; a design not incorporated into current training studies to date (Schwaighofer et al. 2015). This section identifies those important process variables which may account for findings, and is followed by a critique of the implementation process to explore any Type III errors (Dobson & Cook, 1980) which may account for unexpected findings. Type III errors concern those neutral or unexpected findings that perhaps reflect a lack of implementation, which if the implementation process had achieved greater fidelity, may well yield more positive outcomes.

From the outset, dose response and adherence are identified as moderators of training-transfer effects in the training studies literature (Alloway et al. 2013; Morrison & Chein, 2010). Dosage thresholds are considered to support retention of learning across learning contexts (Schmidt & Lee, 1988), and were constant for the WM Condition, but inconsistent in the Numeracy Condition. Cumulative losses from inconsistent dosage thresholds and irregular spacing of training sessions reduced the total duration of training for the Numeracy Condition, with a total of six missed sessions (five sessions, plus cumulative loss from other sessions). While total duration of training is not considered as a moderator of training-transfer effects by Melby-Lervag et al. (2013), it is identified as such by Schwaighofer et al. (2015). Evidence from the implementation audit in this study is consistent with Schwaighofer et al. *(op cit),* and indicates that a lack of adherence to the prescribed duration of training, reduces the intensity of training and subsequently impairs performance and affects motivation for training across the time-point.

Klingberg (2010) posits that spacing of training sessions is not readily considered in most training studies, but is identified in this study as a potential process variable to account for the gains made by the WM Condition relative to the Numeracy Condition. It is not surprising that spacing of training sessions is important to training outcomes in light of earlier evidence presented in chapters 3 and 4 on distributed practice. ‘Little and often’ optimises learning experiences and outcomes, compared to massed practice (Cepeda et al. 2006; Wang et al. 2014). Distributed practice is considered to activate processing and encoding networks that summon more sophisticated retrieval cues from WM (Schooler et al. 1990). In this study, the WM Condition received a consistent daily spacing pattern with training sessions delivered four days per week (with typical three days spacing over the weekend, plus one school day). Conversely, the Numeracy Condition was less consistent, which from staff impact questionnaires and pupil focus groups was reported to impair pupils' sense of coherence in learning. The literature identifies that progress in learning from spaced practice sessions is derived from a regular, distributed practice schedule, which promotes cumulative gains in learning over the longer-term (Schooler et al. 1990).

Evidence from the implementation audit highlights that irregular spacing, poor adherence to dosage recommendations and reduced overall duration of training arose from contextual organisational issues in the school setting. For example, the class teacher in the Numeracy Condition reported the negative impact enduring technology failures had on the implementation process for the computerised numeracy training programme. The implementation checklist (Appendix A) demonstrates that school staff recognised the need for the intervention, yet the impact of technology problems, which the teacher was unable to resolve, may have led to despondency and reluctant to implement the programme at the appropriate dosage or fidelity levels (Ringwalt et al. 2003). These issues suggest that it was not possible for the computerised numeracy training programme to be delivered at a sufficiently challenging pace to engage components of WM or FR, reputed to underpin far-transfer effects (Apter, 2012; Diamond, 2013).

Next, feedback during the training is also important for training-transfer effects (Schwaighofer et al. 2015). The role of feedback varies across training studies for two reasons which include: different programmes have different feedback mechanisms, and secondly, feedback is not consistently reported upon (Melby-Lervag et al. 2013). The value of diverse feedback strategies is identified by pupils in this study as fundamental to enjoyment and motivation for training, being directly related to accounts of acceptability and feasibility of the computerised WM programme, and may partially account for the significant near- and far-transfer effects. In comparison, pupils observed the numeracy programme to actually demotivate at times, particularly as rewards were removed with incorrect responses.

Pupil logbooks were rated highly by most pupils in this study as sources of motivation. Further analysis of the pupil logbooks by the author suggests they would have been more helpful for tracking and monitoring engagement and progress if they gathered more details from pupils after each session. Perhaps, similar to CogMed (2015), a rating scale immediately following every session, and at follow-up, would have been more helpful to understand pupils' experience. While the use of focus groups gathers depth of experience, the method can limit information gathered. It is important to note that sessional progress data is available through the programmes management mechanisms, but has not been reviewed for this study, albeit the author anticipates reviewing the data more fully for the purpose of future publications. It is hoped these reflections offer opportunities to support Truedesson & Strohmayer (2013) establish Memory Quest Flex (Junior) within a wider research-base, and propose the development of pupil process evaluation materials for future replication studies.

A final process variable is the role of the adult, which has more recently been identified as important for effective implementation of training programmes

(Schwaighofer et al. 2015). The WM condition experienced less enduring technology failures relative to the Numeracy Condition, as previously discussed, which allowed the adult to adapt direct levels of scaffolding and support to pupils' needs in line with the pre-defined coach-consult method outlined in Chapter 5, with the class teacher, assuming greater independence. The impact questionnaires from both teachers identified the different levels of coaching support they required and their assumed levels of competence and independence in facilitating training sessions. Interestingly, data from the pupil focus group for the WM Condition indicates their growing sense of independence and competence in class and during training sessions as a result of the training, which mirrors similar developments reported by the class teacher in the impact questionnaire. Patrick, Skinner & Connel (1993) propose rising independence levels can increase an individual's internal sense of control, which promotes the value placed on an activity and improves overall performance outcomes. It is plausible to suggest that the value of the adult in computerised training was maximised by the coach-consult method adopted in this study, and is a possible process variable for positive training-transfer effects.

Overall, strong evidence has been presented to demonstrate Type III errors for the active control, or Numeracy Condition. Therefore, the Numeracy Condition may have experienced greater training-transfer effects, should the numeracy programme have been implemented as planned.

9.3 STUDY LIMITATIONS

9.3.1 Issues with quasi-experimental research designs

This section now turns to the first issue noted earlier about the characteristics of both control groups in this study. Despite the measures taken in this quasi-experimental study design to minimise threats to validity (See Tables 6 to 8 in Chapter 5), precision could be added to the claims about the effectiveness of computerised training programme by full randomisation of conditions to rule out any sampling or selection bias (Torgerson & Torgerson, 2008; 2013). As stated previously, the sample population was limited to those schools the author was the link EP, and were situated within a single locality in the local authority. The schools were matched across various characteristics before randomisation to conditions, but as this was not full randomisation at the individual child level, some artefacts may have influenced the sample, including denominational status or higher levels of deprivation. Therefore, the sample may not have been representative of the Primary 3 school population.

An additional source of bias may arise from the narrow age range (7- 8 years old) of this study, which was selected in line with the research on EF development. However, it is plausible that the age of the sample may partially account for the large effect sizes (Melby-Lervag et al. 2013). Therefore, perhaps for future replication studies, different age ranges could be identified for the computerised training programmes offered here.

Essentially, selection bias and measurement error remain issues for quasi-experimental designs, despite efforts taken to minimise their effects (See Chapter 5 for full discussion). The RCT which offers full randomisation at the individual participant level would allow for greater precision from scrutiny of fully randomised control conditions. However, during times of financial constraint for local authorities in Scotland, the author had access to limited resources which would not make RCT design possible, but is worthy to note for future replication studies.

9.3.2 General issues

A possible limitation of this study is the short follow-up period of three weeks after completion of the computerised training programmes. Inconsistencies across studies make it difficult to identify an optimum follow-up period (Melby-Lervag et al. 2013; Shipstead et al. 2010). Current recommendations emerging in the literature suggest a follow-up period of one year to determine meaningful maintenance and far-transfer effects to educational outcomes (Peijnenborgh et al. 2015). However, this time scale was out-with the scope of this study. Positively, this study did not use immediate post-test follow-up, but used a middle ground timescale of three weeks, in line with Chacko et al. (2013) to measure any maintenance and training-transfer effects, but may not have been long enough to detect longer-term developments in WM or numeracy.

It should also be noted that three statements of the PPNQ were incongruent with the supporting cartoon character, with one of the statements carried forward into the final questionnaire. While the instructions for administration provided the participant with an explanation to deal with this, there may have been some impact on the results which can be investigated further.

All measures in this study were manualised but administered by the author, who was not blind to the study hypotheses or group assignment. However, while researcher bias is noted as a possible threat to the study's validity, all assessments were standardised and administered following the instructions in the respective test manuals. Parallel forms were also used in numeracy.

In 'real-world' classroom-based research it can be difficult to apply systematic experimental procedures (Robson, 2011). In this study, while the four outcome measures were not given in the same order to all pupils, a limitation is that there was no systematic approach to counterbalancing the order of presentation of tasks to fully control for order effects. Future research should address this.

9.4 IMPLICATIONS FOR FUTURE RESEARCH

The previous section illustrated that some threats to validity, while minimised, remain artefacts of the quasi-experimental research design. However, the author holds that selection of the quasi-experimental design of this study communicated ownership of the research with schools from the outset, and allowed for flexibility in gathering rich qualitative data from the implementation audit, which illuminated findings from the quantitative data analysis. Future replication studies could explore the use of a RCT, which would offer greater precision over selection of suitable control conditions to make comparison. Perhaps the gradual encouragement of RCT in educational settings is a promising next step (NfER, 2014).

Closer analysis of the learning processes that inform the substrates of WM, FR and numeracy and which underlie those training-transfer effects observed would be helpful. One approach is for structured observations during training sessions to facilitate deeper analysis of the learning processes that are evidently engaged by adaptive, multi-domain computerised training programmes (Coolican, 2009), such as Memory Quest Flex (Junior). Another candidate approach to support this endeavour is the field of learning analytics (Greller & Drachsler, 2012). Supportive frameworks to measure the learning outcomes from serious games and computerised training programmes include Item Response Theory (IRT), Rasch Models and Structural Equation Modelling (Hung, Hwang, Lee & Su, 2012) and merit further implementation in school settings.

Another point of interest is the reflection that the debate of WM efficiency and capacity remains unresolved. Findings here support claims that Memory Quest Flex (Junior) improves WM capacity through the continuous challenge of WM strategies. However, it is important to note that young children may benefit still further from having WM strategies for efficiency explicitly taught in school, since they do not spontaneously use or expand their strategies until later years (Gathercole, 1998; St Thompson et al. 2010). It may be helpful to conduct further research that combines the teaching of explicit WM strategies alongside computerised WM training to compare their mutual impact on transfer effects for typically developing children and those with WM impairments that require more targeted interventions (Johnson et al. 2010).

9.4.1 Towards a computerised training paradigm in schools

Finally, systematic reviews have attempted to synthesise the diverse range of WM training studies to identify the mechanisms by which computerised training programmes yield near- and far-transfer effects (Melby-Lervag et al. 2013; Morrison et al. 2011; Shipstead et al. 2010). Future directions now turn towards the need for a computerised WM training paradigm (Schwaighofer et al. 2015) that is acceptable and feasible to schools. Findings from this study are offered to address the challenge, and are shown in Table 40.

Table 40

Proposed training paradigm for schools

Training variables	**Components**
Near-transfer effects	Effective when computerised training tasks are similar to tasks measured
Far-transfer gains	Effective when computerised training tasks: • adaptive – offer continuous individualised challenge • cross-modal training tasks that combine visuospatial and verbal WM modalities • underlie executive function of fluid reasoning
Dosage Response	Effective when training tasks: • duration is between 40-50 minutes of 4 sessions per week • consistent daily spacing pattern • adherence to distributed practice sessions over 7 weeks
Motivational pathway	Effective when user interface: • multi-sensory virtual environment • simple embedded narrative • limited choice to scaffold learning experiences
Feedback	Effective when mechanisms: • immediate and positive • diverse and multi-sensory feedback methods • participation of the child with the logbook • reinforcement with summative certificate of completion
Instructional support	Effective supports: • visuospatial modelling with combined verbal explanations provided at the start of a session
Coaching	Effective coaching role: • Coach-consult method to support gradual independent supervision role • monitor engagement and acceptability • maintain regular process notes in the training schedule

9.5 IMPLICATIONS FOR EDUCATIONAL PSYCHOLOGISTS

This section aims to consider the key findings from this thesis in relation to the practice of EPs. EPs are key agents of change in educational settings through their broad core statutory functions of research, consultation, assessment, intervention and training (Birch, Frederickson & Miller, 2015; MacKay, 2013; Scottish Executive, 2002). One clear implication for EP practice arising from this study is that EPs are well-placed to support schools, multi-agency partners, government and policy makers to understand and promote evidence-informed interventions to raise standards in teaching and learning; one of five priorities outlined in the Education (National Priorities) (Scotland) Order (2000) (Boyle, 2011; Cameron, 2006; Meyers, Durlak & Wandersman, 2012). This study provides a strong case for EPs advising on and making important contributions to the implementation variables that underpin evidence-informed teaching and learning approaches (HMIe, 2011), including computerised training programmes, to raise pupil attainment.

Key learning from the literature review demonstrates that numeracy and WM have a unique shared variance, and that the underlying processes of both are imbedded within a wider framework of EFs. The literature review highlighted that successful curriculum experiences that develop numeracy, take account of the central role of WM (and other EFs), and children's perceptions of numeracy. Adaptive, multi-domain computerised WM training programmes, such as Memory Quest Flex (Junior), stand as candidate evidence-informed programmes that offers continuous challenge to improve WM and numeracy performance, and sustain pupil engagement and motivation. The high levels of pupil and staff acceptability of this programme when particular implementation or process variables are in place, is encouraging for EPs. EPs may find it practically helpful when considering implementation of computerised training programmes in schools, to refer to the training paradigm in Table 40 generated from results of this study. Indeed, evidence presented here highlights that consideration of these implementation variables deserves particular attention to avoid Type III errors. Perhaps, the training paradigm and implementation audit of this study could support EPs to analyse school readiness for computerised training programmes and identify those process variables important for training-transfer effects.

The significant findings of this study highlight the value of psychological services carrying out small scale research, evaluating outcomes and exploring processes in order to add to our knowledge of the interventions we deliver. Implications for future directions outlined earlier are intended to hold salience and practical guidance for EPs in their daily challenge to improve teaching and learning outcomes for children using evidence-informed practice. Findings from this study are especially salient since the schools had multiple indicators of deprivation, with pupils at risk of poor learning outcomes. During the writing of this thesis, schools across Scotland with multiple sources of deprivation have been identified for targeted additional resources and funding from the Scottish Government through the National Attainment Challenge. The National Attainment Challenge is the Scottish Government's driver to raise attainment for all, particularly for the most deprived children across Scotland. Educational psychology services are involved in the national response, supporting schools to improve outcomes for children in the areas of numeracy, literacy and health and wellbeing. The author proposes EPs have a key role in supporting schools to design robust small-scale research studies, similar to this study, to inform the National Attainment Challenge and demonstrate improved attainment for the most deprived pupils in Scotland.

9.6 CONCLUSION

This thesis presents strong evidence for near- and far-transfer effects of adaptive, multi-domain computerised WM training with primary-aged school pupils. Selection of the quasi-experimental research design allowed findings to be interpreted within the broader contexts of implementation fidelity to contribute to the literature on the practical and educational value of computerised WM training programmes to improve working memory and numeracy outcomes for primary-school aged pupils.

The author proposes that insights from both computerised training programmes and the important findings about their acceptability and feasibility to staff and pupils offer promise for EPs in supporting schools to deliver excellence and equity of teaching and learning opportunities through evidence-informed practices.

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APPENDICES

APPENDIX A: IMPLEMENTATION READINESS QUESTIONNAIRE

Implementation Science Considerations:
Core Implementation Components to ensure effectiveness of implementation

- Recruitment and Selection:
  - Staff need to be interested, able and willing to put the intervention into practice.
  - Staff should be aware of expectations and any impact upon workload.
  - Staff should be clear regarding the way that the intervention fits with any other work being carried out.
- Pre- and in-service training:
  - In depth training on the topic is needed, both before it is implemented and during implementation, to ensure that staff have a good understanding of knowledge and skills.
- Consultation and Coaching:
  - Coaching has been shown to be a more effective staff development model than stand-alone training.
  - Coaching on skills during implementation and consultation regarding questions or methods those who have provided training is required to ensure staff skills are maintained and developed.
- Staff performance evaluation:
  - Staff need to be monitored in the use of their skills and application of the intervention.
  - Staff must be aware of this monitoring and able to accept feedback.
- Decision support data systems:
  - There should be evaluation of the effects of the intervention, and data should support any conclusions.
  - Staff should be able to support the evaluation and should be aware of expectations on them regarding evaluating the programme.
- Facilitate administrative supports:
  - The intervention should have clear leadership and supports to keep staff skilled and focused.

- Systems interventions:
    - There must be financial, organisational and human resources available to support the project, including linking with the wider context in which the organisation is placed.

Implementation Readiness Questionnaire
Evaluating computerised learning programmes

	YES	NO
Is developing Numeracy / Working Memory and computerised learning a priority for your school?		
Is there time and space for the project in your improvement plan?		
Are staff aware of the project and ready and able to commit to it?		
Have staff had sufficient training to understand the principles underpinning the project?		
Can you free staff up to attend a coaching session and training now and later?		
Can you set aside time for planning and coaching?		
Can you monitor how staff take part in the project?		
Are staff ready to be involved in evaluation and planning as a result?		
Can you collect and collate data to evidence the evaluations?		
Can the Senior Leadership Teams (SLT) commit to prioritising and leading the project?		
Does the organisation as a whole have the resources and supports to carry out the project?		

APPENDIX B: INFORMATION AND CONSENT LETTERS

Dear Sir/Madam,
RE: Access to schools for research

My name is Sharon Brown and I am employed as an Educational Psychologist in X Council. I am undertaking the Doctorate in Educational Psychology programme at the University of Strathclyde. I am writing to request permission to invite schools in X Council to participate in a study. This project aims to develop children's working memory and raise attainment in numeracy through computer-based training programmes. Working memory is central to a wide range of attainment as it is the part of our memory system that allows us to store and manipulate information for learning. Working memory is particularly important for numeracy performance. This project aims to develop children's working memory X Council has invested in numeracy training software which is in place in schools. The authority also has a license for working memory training software which has yet to be evaluated. Benefits of computerised working memory and numeracy training have been reported in the research literature. The aim of this study is to evaluate the effectiveness of computerised working memory training compared to computerised numeracy training as a means of improving working memory and numeracy attainment with primary-aged school pupils.

A total of 72 children aged 7-8 years across three primary schools will be involved in the study as the research literature identifies this age as an important time in children's working memory development. Two classes of Primary 3 children in two different primary schools will take part in the computerised training programme for 7 weeks with 4-5 sessions of computerised training per week. One whole class will receive the computerised working memory training programme and a second whole class will receive the computerised numeracy training programme. Sessions will take place during regular library slots and so there will be minimal disruption to learning. Children will be expected to complete 28 computerised training sessions. A third Primary 3 class will comprise a control group and will receive their regular classroom instruction. The control group will benefit from the computerised training programme that yields positive significant outcomes.

Each child will be asked to:

1. Complete 1 working memory test and 2 reasoning tests. The reasoning test requires children to apply logic and reasoning to choose the missing picture from a selection to complete the pattern and to use the computer to choose if a short string of numbers appear similar or different. This task requires children's attention and planning. The tasks would be carried out at a convenient day/time in a quiet room in school. This process will take approximately 50 minutes.

2. Complete a group numeracy test with other children taking part in the study which will take approximately 30 minutes.

3. Those children in the two treatment groups will train using a computer based programme, either in working memory or numeracy made available in school. The programme will run for 7 weeks. A training session is completed 4-5 sessions per week, lasting approximately 30 minutes.

4. Retake the initial assessments described above. Again this should take about 90 minutes, and ideally would occur within 3-4 weeks of completing the computerised training programme.

A random group of children in each Primary 3 class will be asked to give their views on their experiences of the study in small group interviews. There will be approximately 6-8 children in each group. The group of children will be asked 4- 5 questions. Children whose parents provided consent to participate in the study will be made aware by letter of the date of the group interview and the questions the group will be asked. The group interview would take approximately 20 minutes and will take place in a quiet library area in school during a library slot in their timetable within 3 weeks following completion of the computerised training.

The study will begin on 12th January, 2015, until 30th April, 2015, and take place in the child's school. Written consent will be obtained from parents and children using the attached consent forms. No individual pupils will be identifiable in any written reports. Findings of the study will be shared with the local authority to assist any future planning or implementation. I have been checked by Disclosure Scotland [PVG number- 1107263856940385] and the study has been granted ethical approval by the School of Psychological Sciences and Health Ethics Committee, and by X Council's Educational Psychology Service.

I hope you will allow schools in your authority to take part in this study. I will, of course, be happy to send you a report based on the findings from the research, and would be happy to discuss them with you. If you require any further information, please contact me or my supervisor. If you wish to contact an independent person to whom any questions may be directed or further information may be sought from, you can also contact the Chair of the Ethics Committee, Dr James Baxter.

Yours sincerely,

Sharon Brown
Email: s.brown@strath.ac.uk

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Phone: 0141 548 2242

Dear [insert head teacher's name],

My name is Sharon Brown and employed as the link Educational Psychologist in your school in X Council. I am undertaking the Doctorate in Educational Psychology programme at the University of Strathclyde. I am writing to request permission to invite your school to participate in a study. This project aims to develop children's working memory. Working memory is central to a wide range of attainment as it is the part of our memory system that allows us to store and manipulate information for learning. Working memory is particularly important for numeracy performance. This project aims to develop children's working memory and raise attainment in numeracy through computer-based training programmes. X Council has invested in numeracy training software which is in place in schools. The authority also has a license for working memory training software which has yet to be evaluated. The benefits of computerised working memory and numeracy training have been reported in the research literature. The aim of this study is to evaluate the effectiveness of computerised working memory training compared to computerised numeracy training as a means of improving working memory and numeracy attainment with primary-aged school pupils.

A total of 72 children aged 7-8 years across three primary schools will be involved in the study as the research literature identifies this age as an important time in children's working memory development. Two classes of Primary 3 children in two different primary schools will take part in the computerised training programme for 7 weeks with 4-5 sessions of computerised training per week. One whole Primary 3 class will receive the computerised working memory training programme and a second whole Primary 3 class will receive the computerised numeracy training programme. Sessions will take place during regular library slots and so there will be minimal disruption to learning. Children will be expected to complete 28 computerised training sessions. A third Primary 3 class will comprise a control group and will receive their regular classroom instruction. The control group will benefit from the computerised training programme that yields positive significant outcomes.

I am writing to request that 24 pupils in the Primary 3 class in your school participate in the (insert working memory or numeracy) computerised training programme.

Each child will be asked to:

1. Complete 1 working memory test and 2 reasoning tests. The reasoning test requires children to apply logic and reasoning to choose the missing picture from a selection to complete the pattern and to use the computer to choose if a short string of numbers appear similar or different. This task requires children's attention and planning. Tasks would be carried out at a convenient day/time in a quiet room in school. This process will take approximately 50 minutes.

2. Complete a group numeracy test with other children taking part in the study which will take approximately 30 minutes.

3. Those children in the two treatment groups will train using a computer based programme, either in working memory or numeracy available in school. The programme will run for 7 weeks. A training session is completed 4-5 sessions

per week, lasting approximately 30 minutes.

4. Retake the initial assessments described above. Again this should take about 90 minutes, and ideally would occur within 3-4 weeks of completing the computerised training programme.

A random group of children in each Primary 3 class will be asked to give their views on their experiences of the study in small group interviews. There will be approximately 6-8 children in each group. The group of children will be asked 4- 5 questions. Children whose parents provided consent to participate in the study will be made aware by letter of the date of the group interview and the questions the group will be asked. The group interview would take approximately 20 minutes and will take place in a quiet library area in school within 3 weeks following completion of the computerised training.

The study will begin on 12th January, 2015, until 30th April, 2015, and take place in your school. Written consent will be obtained from parents and children using the attached consent forms. No individual pupils will be identifiable in any written reports. Findings of the study will be shared with the local authority to assist any future planning or implementation. I have been checked by Disclosure Scotland [PVG number- 1107263856940385] and the study has been granted ethical approval by the School of Psychological Sciences and Health Ethics Committee, and by X Council's Educational Psychology Service.

I hope you will allow the Primary 3 in your school to take part in this study following discussion and completion of the readiness questionnaire with Sharon Brown. I will, of course, be happy to send you a report based on the findings from the research, and would be happy to discuss them with you. If you require any further information, please contact me or my supervisor. If you wish to contact an independent person to whom any questions may be directed or further information may be sought from, you can also contact the Chair of the Ethics Committee, Dr James Baxter.

Yours sincerely,

Sharon Brown
Email: s.brown@strath.ac.uk

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Letter to head teacher for control group

Dear [insert head teacher's name],

My name is Sharon Brown, employed as the link Educational Psychologist in your school in X Council. I am undertaking the Doctorate in Educational Psychology programme at the University of Strathclyde. I am writing to request permission to invite your school to participate in a study. This project aims to develop children's working memory and raise attainment in numeracy through computer-based training programmes. Working memory is central to a wide range of attainment as it is the part of our memory system that allows us to store and manipulate information for learning. Working memory is particularly important for numeracy performance. X Council has invested in numeracy training software which is in place in schools. The authority also has a license for working memory training software which has yet to be evaluated. The benefits of computerised working memory and numeracy training have been reported in the research literature. The aim of this study is to evaluate the effectiveness of computerised working memory training compared to computerised numeracy training as a means of improving working memory and numeracy attainment with primary-aged school pupils.

A total of 72 children aged 7-8 years across three primary schools will be involved in the study as the research literature identifies this age as an important time in children's working memory development. Two Primary 3 classes in different primary schools will take part in the computerised training programme for 7 weeks with 4-5 sessions of computerised training per week. One whole Primary 3 class will receive the computerised working memory training programme and a second whole Primary 3 class in a different primary school will receive the computerised numeracy training programme. Sessions will take place during regular library slots and so there will be minimal disruption to learning. Children will be expected to complete 28 computerised training sessions. A third class of Primary 3 children from a third primary school will comprise a control group and will receive their regular classroom instruction.

I am writing to request that 24 pupils in the Primary 3 class in your school participate in the study as the control group. The control group will benefit from the computerised training programme (either the computerised working memory programme or computerised numeracy training programme) that yields positive significant outcomes.

Each child in the control group will be asked to:

1. Complete 1 working memory test and 2 reasoning tests. The reasoning test requires children to apply logic and reasoning to choose the missing picture from a selection to complete the pattern and to use the computer to choose if a short string of numbers appear similar or different. This task requires children's attention and planning. The tasks would be carried out at a convenient day/time in a quiet room in school. This process will take approximately 50 minutes.

2. Complete a group numeracy test with other children taking part in the study which will take approximately 30 minutes.

3. Children will continue to receive regular classroom instruction.

4. Retake the initial assessments described above. Again this should take about 90 minutes, and would take place in March/April, 2015.

The study will begin on 12th January, 2015, until 30th April, 2015. Written consent will be obtained from parents and children using the attached consent forms. No individual pupils will be identifiable in any written reports. Findings of the study will be shared with the local authority to assist any future planning or implementation. I have been checked by Disclosure Scotland [PVG number-1107263856940385] and the study has been granted ethical approval by the School of Psychological Sciences and Health Ethics Committee, and by X Council's Educational Psychology Service.

As the control group, the Primary 3 class would benefit from the computerised training programme (either the computerised working memory programme or computerised numeracy training programme) that yields positive significant outcomes. The programme would be offered on 31st August, 2015, until 9th October, 2015. Staff would be fully supported with the implementation and evaluation of the programme by Sharon Brown.

I hope you will allow the Primary 3 class in your school to take part in this study as a control group. I will, of course, be happy to send you a report based on the findings from the research, and would be happy to discuss them with you. If you require any further information, please contact me or my supervisor. If you wish to contact an independent person to whom any questions may be directed or further information may be sought from, you can also contact the Chair of the Ethics Committee, Dr James Baxter.

Yours sincerely,

Sharon Brown
Email: s.brown@strath.ac.uk

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Letter to parent / guardians for both treatment groups

Dear [insert Parent/Carer's name],
My name is Sharon Brown and I am employed as the link Educational Psychologist in (insert primary school name) in X Council. I am undertaking the Doctorate in Educational Psychology programme at the University of Strathclyde. I am writing to request permission to invite your child (insert child's name) to participate in a study. This project aims to develop children's working memory and raise attainment in numeracy through computer-based training programmes. Working memory is central to a wide range of attainment as it is the part of our memory system that allows us to store and manipulate information for learning. Working memory is particularly important for numeracy performance. This project aims to develop children's working memory X Council has invested in numeracy training software which is in place in schools. The authority also has a license for working memory training software which has yet to be evaluated. The benefits of computerised working memory and numeracy training have been reported in the research literature. The aim of this study is to evaluate the effectiveness of computerised working memory training compared to computerised numeracy training as a means of improving working memory and numeracy attainment with primary-aged school pupils.

Around 72 children aged 7-8 years across three primary schools will be involved in the study as the research literature identifies this age as an important time in children's working memory development. Two Primary 3 classes will take part in the computerised training programme for 7 weeks with 4-5 sessions of computerised training per week. One class will receive the computerised working memory training programme and a second class will receive the computerised numeracy training programme. Sessions will take place during regular library slots and so there will be minimal disruption to learning. Children will be expected to complete 28 computerised training sessions. A third class of children will comprise a control group and will receive their regular classroom instruction. The control group will benefit from the computerised training following the study should the study yield positive significant outcomes.

I am writing to invite (insert child's name) to take part in the (insert working memory or numeracy) computerised training programme alongside the rest of the Primary 3 class at (insert primary school name).

Your child will be asked to:

1. Complete 1 working memory tests and 2 reasoning tests. The reasoning test requires children to apply logic and reasoning to choose the missing picture from a selection to complete the pattern and to use the computer to choose if a short string of numbers appear similar or different. This task requires children's attention and planning.The tasks would be carried out at a convenient day/time in a quiet room in school. This process will take approximately 50 minutes.

2. Complete a group numeracy test with other children taking part in the study which will take approximately 30 minutes.

3. Train using the (insert working memory or numeracy) computer based programme. The programme will run for 7 weeks. A training session is completed approximately 4-5 sessions per week, lasting approximately 30 minutes.

4. Retake the initial assessments described above. Again this should take about 90 minutes, and ideally would occur within 3-4 weeks of completing the computerised training programme.

Some children in each Primary 3 class will be randomly asked to provide their views on their experiences of the study in small group interviews. There will be approximately 6-8 children in each group. The group of children will be asked 4- 5 questions. Children whose parents provided consent to participate in the study will be made aware by letter of the date of the group interview and the questions the group will be asked. The group interview would take approximately 20 minutes and take place during a library slot in the school timetable within 3 weeks following completion of the computerised training.

The study will begin on 12th January, 2015, until 30th April, 2015, and take place in (insert primary school name). All responses your child gives will be confidential. In addition, all information provided on the consent form will be kept confidential and will not be linked to the responses your child gives. Findings of the study will be shared with the local authority to assist any future planning or implementation.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998. I have been checked by Disclosure Scotland [PVG number-1107263856940385].

I hope that you will allow your child to participate. However, this study is entirely voluntary, and you or your child can opt not to take part. All children will confirm whether or not they wish to take part, and it will also be made clear to your child that they can stop taking part even after they have started completing the tasks without giving a reason and without any consequences.

Please complete the attached consent form to indicate whether you DO or DO NOT wish your child to take part, and return the consent form to the school.

This investigation was granted ethical approval by the School of Psychological and Health Sciences Ethics Committee. If you have any questions about the study, please contact me or my supervisor, Professor James Boyle. If you wish to contact an independent person to whom any questions may be directed or further information may be sought from, you can also contact the Chair of the Ethics Committee, Dr James Baxter.

Yours sincerely,

Sharon Brown
Email:s.brown@strath.ac.uk

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Dear [insert Parent / Carer's name],

My name is Sharon Brown and I am employed as the link Educational Psychologist in (insert primary school name) in X Council. I am undertaking the Doctorate in Educational Psychology programme at the University of Strathclyde. I am writing to request permission to invite your child, (insert child's name) to participate in a study. This project aims to develop children's working memory and raise attainment in numeracy through computer-based training programmes. Working memory is central to a wide range of attainment as it is the part of our memory system that allows us to store and manipulate information for learning. Working memory is particularly important for numeracy performance. This project aims to develop children's working memory in X Council has invested in numeracy training software which is in place in schools. The authority also has a license for working memory training software which has yet to be evaluated. The benefits of computerised working memory and numeracy training have been reported in the research literature. The aim of this study is to evaluate the effectiveness of computerised working memory training compared to computerised numeracy training as a means of improving working memory and numeracy attainment with primary-aged school pupils.

Around 72 children aged 7-8 years across three primary schools will be involved in the study as the research literature identifies this age as an important time in children's working memory development. Two Primary 3 classes in different primary schools will take part in the computerised training programme for 7 weeks with 4-5 sessions of computerised training per week. One class will receive the computerised working memory training programme and a second class will receive the computerised numeracy training programme. Sessions will take place during regular library slots and so there will be minimal disruption to learning. Children will be expected to complete 28 computerised training sessions. A third Primary 3 class will comprise a control group and will receive regular classroom instruction. The control group will benefit from the computerised training (either the computerised working memory training or the computerised numeracy training programme) that yields positive significant outcomes following the study.

I am writing to invite (insert child's name) to take part in the control group alongside the rest of the Primary 3 class.

Your child will be asked to:

1. Complete 1 working memory test and 2 reasoning tests. The reasoning tests requires children to apply logic and reasoning to choose the missing picture from a selection to complete the pattern and to use the computer to choose if a short string of numbers appear similar or different. This task requires children's attention and planning. The tasks would be carried out at a convenient day/time in a quiet room in school. This process will take approximately 50 minutes.

2. Complete a group numeracy test with other children taking part in the study which will take approximately 30 minutes.

3. Receive regular classroom instruction.

4. Retake the initial assessments described above. Again this should take about 60 minutes, and ideally would occur within 3-4 weeks of completing the computerised training programme.

The study will begin on 12th January, 2015, until 30th April, 2015, and take place in (insert primary school name). All responses your child gives will be confidential. In addition, all information provided on the consent form will be kept confidential and will not be linked to the responses your child gives. Findings of the study will be shared with the local authority to assist any future planning or implementation.

The University of Strathclyde is registered with the Information Commissioner's Office who implements the Data Protection Act 1998. All personal data on participants will be processed in accordance with the provisions of the Data Protection Act 1998. I have been checked by Disclosure Scotland [PVG number-1107263856940385].

As the control group, the Primary 3 class would benefit from the computerised training programme (either the computerised working memory programme or computerised numeracy training programme) that yields positive significant outcomes. The programme would be offered on 31stAugust, 2015, until 9th October, 2015. Staff would be fully supported with the implementation and evaluation of the programme by Sharon Brown

I hope that you will allow your child to participate. However, this study is entirely voluntary, and you or your child can opt not to take part. All children will confirm whether or not they wish to take part, and it will also be made clear to your child that they can stop taking part even after they have started completing the tasks without giving a reason and without any consequences.

Please complete the attached consent form to indicate whether you DO or DO NOT wish your child to take part, and return the consent form to the school.

This investigation was granted ethical approval by the School of Psychological and Health Sciences Ethics Committee. If you have any questions about the study, please contact me or my supervisor, Professor James Boyle. If you wish to contact an independent person to whom any questions may be directed or further information may be sought from, you can also contact the Chair of the Ethics Committee, Dr James Baxter.

Yours sincerely,

Sharon Brown
Email: s.brown@strath.ac.uk

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School: School of Psychological Sciences & Health.
Title of Study: Developing working memory and numeracy in primary-aged school pupils:
Evaluating the effectiveness of computerised training programmes

- I confirm that I have read and understood the information sheet for the above project and the researcher has answered any queries to my satisfaction.

- I understand that my child's participation is voluntary and that I am free to withdraw my child, and my child can withdraw from the project at any time, without having to give a reason and without any consequences

- I understand that I can withdraw my child's data from the study at any time before completion of the study, but that it will not be possible to withdraw the data once they have completed the study as all information gathered will be anonymous and individual data therefore cannot be identified

- I understand that I can withdraw my child's data from the study at any time. [do not include this bullet if data cannot be withdrawn – e.g. anonymous questionnaires or focus groups]

- I understand that any information recorded in the investigation will remain confidential and no information that identifies me or my child will be made publicly available.

- I consent to my child being a participant in the project.

Name of Child:____
(please print)

Print Name (Parent/Guardian):	Hereby agree to my child taking part in the above project.
Signature of Parent/Guardian:	Date:

APPENDIX C: RECORD OF PUPIL VERBAL CONSENT

Participant Name	Verbal Consent Obtained (Y/N)	Verbal debrief completed (tick when completed)

APPENDIX D: PUPILS' PERCEPTIONS OF NUMERACY QUESTIONNAIRE

Name: ________________________________
School: ________________________________
Date: __________________________

Practice items

1. Circle the sentence when you think **"this is like me"**

Some kids forget what they learn **Some kids remember things easily**

Really true of me **Sort of true for me**

2. Circle the sentence when you think **"this is like me"**

Some kids do not like sweets **Some kids like sweets**

Really true of me **Sort of true for me**

<u>Test items</u>

1. Circle the sentence when you think **"this is like me"**

Some kids find number hard

Some kids find number easy

Really true of me

Sort of true for me

2. Circle the sentence when you think **"this is like me"**

Some kids hate number

Some kids like number a lot

Really true of me

Sort of true for me

3. Circle the sentence when you think **"this is like me"**

Some kids worry about number **Some kids feel relaxed about number**

Really true of me **Sort of true for me**

4. Circle the sentence when you think **"this is like me"**

Some kids do not understand what the teacher says in number **Some kids find the teacher easy to understand in number**

Really true of me **Sort of true for me**

5. Circle the sentence when you think **"this is like me"**

Some kids do not like doing number on the computer

Some kids enjoy doing number on the computer

Really true of me

Sort of true for me

6. Circle the sentence when you think **"this is like me"**

Some kids get sad if they do badly

in number

Some kids feel ok if they do badly in number

Really true of me

Sort of true for me

Well done

APPENDIX E: PUPIL FOCUS GROUP QUESTIONS

1. What computerised training programme did your class take part in?
2. How was Memory Quest Flex set up in your school?
3. Did Memory Quest Flex help you with your school work?
4. What school work or skills did the programme help you with?
5. How did the programme help you with your school work / skills?
6. What did you enjoy the most about Memory Quest Flex?

APPENDIX F: PUPIL FOCUS GROUP TRANSCRIPTS

WM CONDITION FOCUS GROUP TRANSCRIPT

Date: **26.06.15 6 children**

Questions will be used in a focus group conversation with a stratified randomised sample of 6-8 children from the Primary 3 class, balanced for gender. Their responses will be recorded on the recording sheet.

Focus Group Questions

1. What computerised training programme did your class take part in?
2. How was Memory Quest Flex set up in your school?
3. Did Memory Quest Flex help you with your school work?
4. What school work or skills did the programme help you with?
5. How did the programme help you with your school work / skills?
6. What did you enjoy the most about Memory Quest Flex?
7. What did you least enjoy about Memory Quest Flex?

1. What computerised training programme did your class take part in?	We took part in Memory Flex (responses of 4 children: ID/Gender-**3/F, 6/M, 7/M, -2/F**) It was called Memory Quest (1 child: ID/Gender- **10/F**) We met in the computer room every day and played games remembering lists and pictures of things, it was a memory game on the computer, can't remember its name (1child; ID/Gender- **1/M**).
1. How was Memory Flex set up in your school?	**6/M** - We went to the computer room in groups. My group was first to go after lunchtime. We went on the same PCs after we typed in our special number to play the memory games with all the funny games and little avatars. There were lots to look at with all the bright colours, it was great!. We ticked the book at the end of every day when we finished. We had a special pen. **7/M**- Most days our teacher took us, and sometimes you took us to the computer room to do memory games. We logged on with our passwords and saw the treasure map. You helped us if the game stopped working. I learned how to sort it myself after a few times. The treasure map helped me to see what I still had to do. **-2/F**- We went with you when our teacher could not take us. We sat mostly at the same computer and had our own password to start. The log books were good and showed how far I got every day. After we played the games, we got to decorate the spaceship. **10/F**- We work through the treasure map every day to play the memory games. I had a lot of rewards and ticked my log book after I finished so I could get a certificate and class rewards. **1/M** -My computer was broken a few times and you helped me. I got better at the games when I tried them a few times but they were a bit easy. It was good having the games every day and in small groups. It wasn't as noisy as class. I got to the end of the games after few weeks I got faster. **3/F**- My group went to the computer room and logged onto the game. We stopped early to tick the log book every day. Our teacher chatted with you and we got to pick special rewards each week. I also got a certificate at the end. It was good fun.
2. Did Memory Flex help you with your school work?	**-2/F** -It helped me remember what the teacher said or wrote on the board. I can work on my own more. **3/F**- The game helped me to concentrate in class because I had to concentrate and look hard at all the different games and colours. Sometimes they were moving pictures and sometimes I had to listen to the different music to remember the different music. That helped me to pay attention more in class to the teacher and helpers. **6/M**- Yes, I got better at listening to the teacher and doing work on my own in my jotters. **3/F**- I liked the games and liked finding out what I had to do next. I got better at the games and what I was to do. I liked playing games and getting rewards, and counting points. After I played it a few times, I felt better in class because I can listen to the teacher and its helped me get better at counting. **7/M-**Memory games were fun and helped me to stop fidgeting. I can sit longer now and feel calmer in my seat 'cause I don't have to get up as much. I can listen better now. **1/M**- Not really...it didn't help me with anything.

3. What school work or skills did the programme help you with? **1/M:**Not sure – I don't know. *Child did not offer any other answer.*	**3/F**- The programme helped me remember timetables because I used to always forget them. I remember my numbers faster when I'm doing my sums. The game helped me to think about more things at the same time. **6/M**- The memory games helped me write more because I can get my answers faster in my head. **10/F**- I'm a better speller now after the programme because I am more careful of getting words wrong. The memory games have helped me to think of what the word looks like. I can then use my spelling strategies to write it. **7/M**- I remember what the teacher has told me more and think the memory games have helped me to remember lots of things she says. I don't get so worried about doing stuff in class. **-2/F-**My Mum says my homework is better because I don't take so long to do it now. I think I know what I have to do now and do it more on my own.I don't get so upset with my homework. I give it a try.
4. How did the programme help you with your school work / skills? **1/M:** Not sure – shrugged shoulders *Child did not offer any other answer*	**3/F-**I can try stuff on my own more now without the teacher's help. I can remember what I have to do. **-2/F**- I finish my work now and I get time to play afterwards. I used to get lots of work to do at playtime or at home time and I don't really get that now because I finish it in class. **10/F**- I remember more, like I can remember more of what is written on the board. When the teacher rubs it off the board to fast, I just remember it now. I can understand her more now. **6/M**- Playing the games on the computer has helped me remember to check my jotter. It has helped all my writing but story writing is better because I remember to go back and check my full stops. I also remember now to use finger spaces. I have had Star Writer award. I'm not so worried now. **7/M-** I am better at listening cause I am not making mistakes with my work. I do it right first time now.
5. What did you enjoy the most about Memory Flex?	**1/M-** Following the treasure map was fun and easy… a bit boring after a while, but it did stop me rushing ahead everyone. The games were good because they were like things we get asked to do, like remember noises or when we are sent a message. **6/M**- I liked having my avatar – it helped me get to the treasure chest. The treasure map helped me know what games I had done and what I still had to try every day. 4 children enjoyed the games / puzzles with point rewards (**3/F, -2/F, 10/F, 6/M**). 3 children enjoyed the reward of decorating the spaceship and being able to tick their logbooks (**6/M, 7/M, 3/F**). 2 children said the log book helped them to see how well they were doing (**6/M. 7/M**). 1 child said the logbook was a "challenge to keep getting better"(**7/M**). 1 child said the logbook was "fun" and "it felt good when I got to tick the logbook because I'd worked hard on the games" (**10/F**). All children enjoyed receiving the certificate at the end of training. **6/M**- I liked the music and sounds in the different games and after each answer because I would know if I got it right or got a reward. It helped me to keep going round the treasure map. **10/F**- It was good because we did it every day and I got better. I can do it so fast on my own now. It was great doing it every day. **3/F**-Can the school use Memory Flex? It really helped me be careful to listen and look and not to make as many mistakes with my work. It would be good to use in class when we do maths and spelling.
6. What did you least enjoy about Memory Flex?	**6/M, 10/F**- Sometimes the pictures were hidden and I couldn't see them but had to click on the screen where I thought they would be. Like in the magician's table game. I didn't get many points for that game. **7/M-** As above, but for the town square game. **1/M-**It was annoying and was unfair when my computer didn't work and I had to change to another one when everyone else's was ok. **-2/F, 10/F**- The programme sometimes stopped working but you sorted it. It was annoying. (Internet connection failed).

NUMERACY CONDITION FOCUS GROUP TRANSCRIPT

Date: **26.06.15 6 children**

Questions will be used in a focus group conversation with a stratified randomised sample of 6-8 children from the Primary 3 class, balanced for gender. Their responses will be recorded on the recording sheet.

Focus Group Questions

1. What computerised training programme did your class take part in?
2. How was Study Ladder Maths set up in school?
3. Did Study Ladder Maths help you with your school work?
4. What school work or skills did the programme help you with?
5. How did the programme help you with your school work / skills?
6. What did you enjoy the most about Study Ladder Maths?
7. What did you least enjoy about Study Ladder Maths?

WHAT COMPUTERISED TRAINING PROGRAMME DID YOUR CLASS TAKE PART IN?	1 child said a maths games on the computer (ID/Gender: **45/M**). 1 child said Maths Success (ID/Gender: **44/F**) 4 children said Study Ladder Maths (ID/Gender: **24/F, 27/F, 31/M, 36/M)**
HOW WAS STUDY LADDER MATHS SET UP IN YOUR SCHOOL?	**36/M**- I went to the computer room with my teacher and went with you a few times. I went every day most times for a long time. I sat at the same computer usually but 1 or 2 times I used the iPad. It was quicker to start up. I went onto the maths games and tried different ones. I could choose different maths games every day and then there was time at the end for rewards. Then I had to tick my logbook. Sometimes I forgot that bit. **44/F**- Primary 3s went to the computer room in 3 groups. I had a password to type in which took me a bit longer. I got better with it. The maths games were good because I got to pick which one I played and it spoke to you to tell you what to do and if you got stuck it sometimes helped you. If you got the answer correct you got a point that was saved up. When I finished I could use up the points to buy a reward for my avatar. I loved my avatar and got to buy clothes for her with the reward points. She was a lucky avatar! **27/F-** I went with my group every day to the computer and played Study Ladder Maths to help me with maths. It was lots of maths games. They were sometimes too hard but I could just pick another game to try. I had my logbook with me to tick when our time was up in the computer room. Some days I forgot to tick my log book. I'm not sure …we did look at our logbooks with you. **45/M-** One time I shared a computer because my computer wouldn't work. I got fed up and it not working made me think the programme wasn't so good really. The next time the computer never worked so I used an iPad to play the maths games. It was better and faster. The games were ok but sometimes couldn't remember which ones I had done. **31/M-** My group went to the computer room together and we sat at a computer to play the number games. Sometimes we were there with you, or the teacher took us a few times. I had to put on the door the poster to say we were busy. The games were fun but sometimes I wish I had more time to play the reward games with the avatar. I liked when the teacher gave us rewards every week in the class because we had tried hard with the computer games. That was fun and she was proud of us. **24/F**- I went to play the maths games every day in my group- I liked that time when we got to go. We picked some games to play to help our maths and filled out our logbooks after wards to show how we were doing. We got time to play reward games and got a certificate at the end.
DID STUDY LADDER MATHS HELP YOU WITH YOUR SCHOOL WORK?	Yes the programme helped with school work (3 children, all nodding, **44/F, 24/F, 36/M**) **27/F**- I don't think it helped me cause it was too hard **31/M**- No, it didn't help me with my work in school really **45/M**- It was a bit tricky ... to use it.

WHAT SCHOOL WORK OR SKILLS DID THE PROGRAMME HELP YOU WITH?	**45/M-** The programme hasn't helped me with maths in class because I'm still not so good at it. **44/F**- I can think about more stuff and not get muddled up so now I can think of answers and use my number square to find the answer. **24/F-** It helped me to understand the teacher, like when we do bigger and smaller, I get that now. **36/M-** I can count better making fewer mistakes. My sums are neater in my jotter because I am not rubbing out so much. I practised adding on the computer and it helped me do adding sums better. I can work more on my own now. **31/M**- I don't think my school work is different. It's just the same. **27/F**- No not really (shrugged shoulders)
HOW DID THE PROGRAMME HELP YOU WITH YOUR SCHOOL WORK / SKILLS?	**36/M**- I am faster at working out different things in my head and getting an answers because the programme had a game with a big clock and we had to beat different avatars. I didn't beat them but can do more now and I am faster with my maths in class. **31/M**- I am doing ok in my number work. Study Ladder Maths is ok, I'm not sure if it helped me get better at work in school. **44/F**- It made my brain work and I can do more in maths and in language now, I can think faster. **24/F**- I can remember more numbers in my head and work with bigger numbers because I worked hard on the maths problems in Study Ladder Maths. **27/F**- I don't really know it if it helped me in school. I don't think so really. **45/M**- No, it never ...I don't think it did help any.
WHAT DID YOU ENJOY THE MOST ABOUT STUDY LADDER MATHS?	**44/F**- It was good because we went a lot and so I got to practice and work on my own and try things out ...it helped because I worked on my own on the computer games. I liked when I played against the avatars (3 children: **44/F, 24/F, 36/M**) I liked earning points to spend on rewards (2 children: **36/M, 24/F**) **31/M**- I think the logbook was ok, it helped me keep up with everyone and I knew how I was doing, it felt good. I enjoyed reward time in class on a Friday and I got to colour in my logbook if I wanted to. **27/F**- Having time in small groups was good, it was quieter to help me try hard, but the games were too hard. **45/M**- Don't know, it was a bit boring and too hard to find the games.
WHAT DID YOU LEAST ENJOY ABOUT STUDY LADDER MATHS?	I got a bit upset and didn't like getting the answers wrong when it made a loud sound and took away points (2 children: **27/F, 31/M**) **26/M, 31/M** - I didn't like the games against the avatars because they were timed games and I never beat them. They always won. **31/M-** Our teacher sometimes forgot the logbooks. **45/M, 31/M**- Sometimes I couldn't remember what games I had tried and forgot the ones I had done and sometimes went back to the same game the next day. **27/F**- The games were boring. The voices telling you what to do were slow. **24/F-** We were all playing different games and you could pick any game – some boys just picked the difficult games straight away and they were too hard for them anyway.

Memory Quest Flex

Logbook for ______________________________

Welcome to your log book!

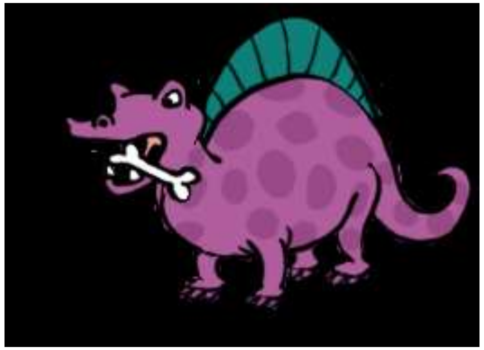
This is your Memory Quest training log book. It provides information on working memory or WM and how the training works.

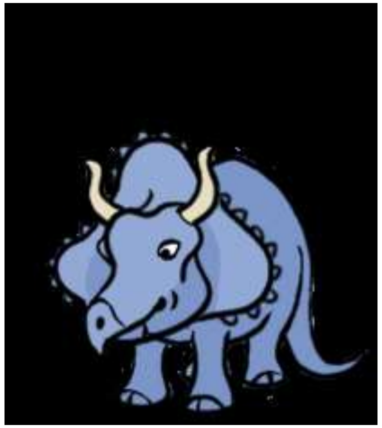
WM

WM has been discussed for about 50 years. It is used describe how you keep and use information in your head for a short time.

This may not seem so remarkable, but the fact is that you use WM every day - many times.

You use WM when you read a magazine, do some writing or solve a tricky problem. You also use it when you solve a maths problem in school, or follow your teacher's instructions. For some years it has been known that it is possible to train WM.





Examples of when you use your WM

Example 1

You meet a friend and her mother on the way home from school. You want to call your friend but you do not have her number. Your friend tells you her home phone number.

30 57 43

You must now try to remember the number until you get home. On the way home you say the number silently to yourself many times to remember it. When you get home you write the number down on a piece of paper.

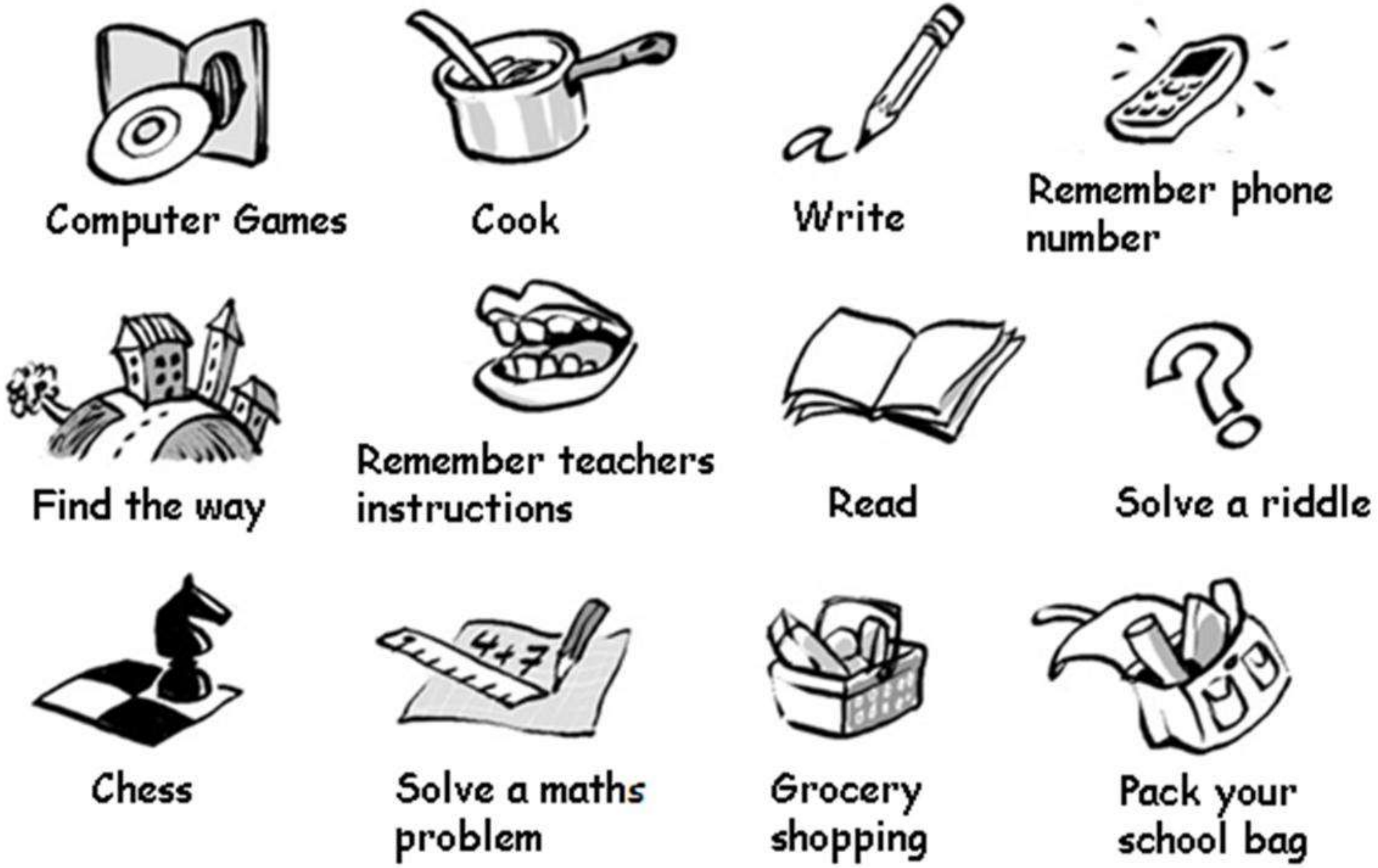
Example 2

On Saturday you are going to a school friend's party. You have never been to his home before, but he lives nearby so you will walk to the party without your parents. You have the address on the invitation, but you are still a bit unsure of how to find your way.

Your parents describe the way for you one more time just before you leave home. "First go straight on until you reach the large playground. There you turn left and carry straight on until you reach the red school. When you reach the school, turn right and go straight on until you come to a street with houses on both sides. Your friend's house is the third on the left. Make sure it is number 14 and painted yellow."

To remember the way you have to keep the description in your head. You have to remember the places you will pass, (the large playground and the red school). In addition, you must remember if you are supposed to go straight on, left or right at the different locations (first left, then right) and at which house the party will be held (the third on the left, number 14, painted yellow).

More examples of when you use WM



Memory Quest Flex

Memory Quest is designed to train your WM. After using Memory Quest you will probably find some things easier at school. Some things that may improve are your concentration, writing stories and remembering what to bring home from school. You may also find it easier to remember phone numbers, to find the way to a new place and to remember what to buy at the shops.

Training WM takes time. It has been shown to be important that you train every day and that you train for the whole period of time that has been planned. It is most common to train five times a week for five weeks. Therefore it is different from most other training you may have done. If you want to get better at football, dancing or playing the guitar it is enough to train two or three times a week, and it doesn't matter if you miss training from time to time.

It is different when you train your WM. It is important that you do not take any breaks from the training. For it to have an effect you must train every day that has been planned. It is also important that you do your best. If you do not really try to complete each task successfully, the training does not work. This does not mean that you must successfully solve each task. The fact is that for the training to have the most effect it should sometimes be a bit too hard.

Rewards

Memory Quest training is sometimes fun and sometimes difficult. It is very important that you complete all the training sessions. For doing your training you get a reward every five days. If you can't think of any suitable rewards there are some ideas on the right. Write or paste in pictures of the rewards you choose at the bottom of the schedule for each week.

Examples of Rewards

Playground games with your class

Baking with the class

Trip to the cinema

Reading a class book

Pizza in the sensory garden

Picnic at the local park

Check list before you begin

- There is an adult responsible for your training (and someone who is responsible when he or she is absent)
- You know where to sit when you train (it must be a room where you can be completely undisturbed)
- Together with your coach you have planned the number of training sessions and when you will train
- Your coach has talked to you about why it is good to train with Memory Quest
- You have read your log book carefully
- You have written or pasted rewards in the log book
- You have decided to train the whole training period and to always try your best
- Check list - before you begin with your coach you have planned the number of training sessions and when you will train (usually four times a week for seven weeks)
- You have decided to train for the whole training period and always to try to do your best

Now all the preparations are finished! Good luck with the training!

Training week 1

Now the training begins! Good luck!

Colour in a circle at the end of each training day.

Day 1

Day 2

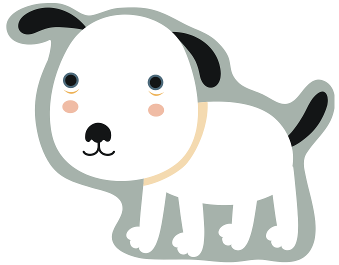
Day 3

Day 4

You have completed your first week of training and deserve a reward!

Reward week 1:

____



Training week 2

Now the second week begins!
Keep up the good work!

Day 8

Day 6

Day 5

Day 7

Now you have completed the second week of training and deserve a reward!

Reward week 2:

____

Training week 3

Now the third week of training begins. Almost half way! Good luck with the training!

Day 11

Day 12

Day 10

Day 9

Now you have completed the third week of training and deserve a reward!
Reward week 3:

____

Training week 4

Time for the fourth week of training.
Just two weeks to go!

Day 13

Day 14

Day 15

Day 16

Now you have completed the fourth week of training and deserve a reward!

Reward week 4:

____

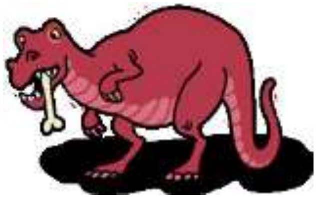
Training week 5

Now the last week of training begins!
You have almost finished the training!

Day
20

Day
19

Day
18



Now you have finished your last week of training and really deserve a reward!
Reward week 5:

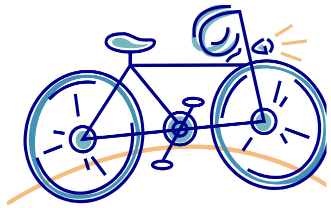
____

Day
17

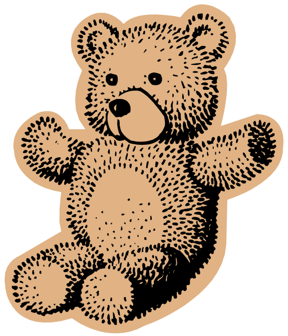
Training week 6

More than half way there!

Keep up the good work!



Day 24



Day 23

Day 22

Day 21

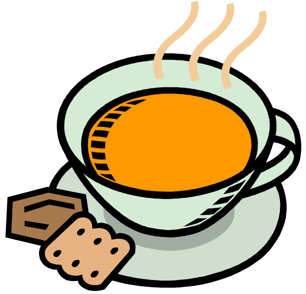
Now you have completed the sixth week of training and deserve a reward!

Reward week 6:

____

Training week 7

Now the last week of training begins. You have almost finished the training!

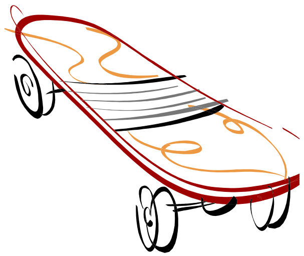


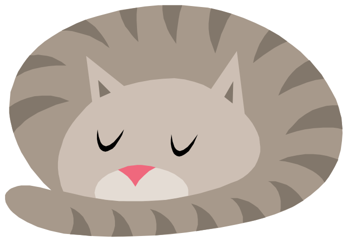
Day 25

Day 26

Day 27

Day 28





Now you have finished your last week of training and really deserve a reward!

Reward week 7:

____

Congratulations!

Your training is now complete!




Study Ladder Maths

Logbook for: ___________________________

Welcome to your logbook!

It gives information on how the training works and helps you record your training from day to day.

Why should I train with Study Ladder?

We might thin numeracy is something we only do in school, but we use it every day. For example, you use numeracy when we visit the shops and you know how much money you have to spend and how much change we get back. Your numeracy skills also help you to know how much different ingredients to use when baking. Numeracy is very useful!

Study Ladder

Study Ladder is software to help you train your numeracy skills. Study Ladder aims to help you with numeracy and get better with numbers and counting. Study Ladder might help you to think numeracy is fun!

When you train with Study Ladder, there are a few things to remember. Training numeracy skills takes time. It has been shown to be important that you train every day and that you train for the whole period of time that has been planned. It is most common to train four times a week for seven weeks. It is a bit different to other training. If you want to get better at football, dancing or playing drums it is enough to train two or three times a week, and it doesn't matter if you miss training from time to time.

It is different when you train with Study Ladder. It is important that you do not take any breaks from the training. For it to have an effect you must train every day that has been planned. It is also important that you do your best. If you do not really try to finish each task successfully, the training does not work. This does not mean that you must successfully solve each task. The fact is that for the training to have the most effect it should sometimes be a bit too hard.

Worth thinking about!
Some people think numeracy is something that you are either good or bad at, and that you can do nothing to get better. That is not true. As with football, or to draw, it is training that makes you better. However, we all differ in how difficult things are for us to learn, so some people may need to train more than others.

Rewards

Study Ladder training is sometimes fun and sometimes difficult. It is very important that you finish all the training sessions. For doing your training you get a reward every five days in school. If you can't think of any rewards there are some ideas on the right.

Examples of Rewards

Picnic with the class

Read a favourite book with your teacher

Watch your favourite movie in class

Visit a museum together

Check list before you begin

- There is a coach responsible for your training (and someone who is responsible when he or she is absent)
- You know where to sit when you train (it must be a quiet room)
- Your coach has talked to you about why it is good to train with Study Ladder
- You have read your log book carefully
- You have talked to your teacher about rewards
- You have talked to your coach to plan the number of training sessions and when you will train (usually four times a week for seven weeks)
- You have decided to train for the whole training period and always to try to do your best

Now you are ready!
Good luck with the training!

Training week 1

Now the training begins! Good luck!

Colour in a circle at the end of each training day.

Day 1

Day 2

Day 3

Day 4

You have completed your first week of training and deserve a reward!

Reward week 1:

Training week 2

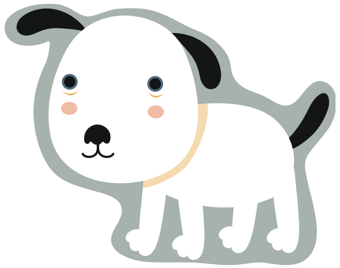
That wasn't so hard!
Let's do it again!

Day 8

Day 6

Day 7

Day 5



Now you have completed the second week of training and deserve a reward!

Reward week 2:

Training week 3

Now the third week of training begins. Almost half way! Good luck!

Day 12

Day 10

Day 11

Day 9

Now you have completed the third week of training and deserve a reward!

Reward week 3:

Training week 4

Time for the fourth week of training.
Three down four to go!

Day 13

Day 14

Day 15

Day 16

Now you have completed the fourth week of training and deserve a reward!
Reward week 4:

Training week 5

More than half way there!
Keep up the good work!

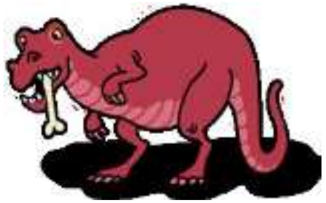
Day
20

Day
18

Day
19

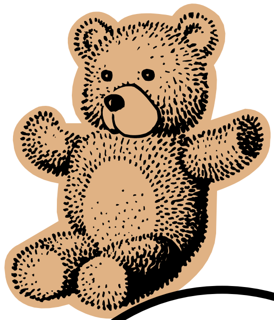
Day
17

Now you have completed fifth week of training and deserve a reward!
Reward week 5:



Training week 6

More than half way there!
Keep up the good work!



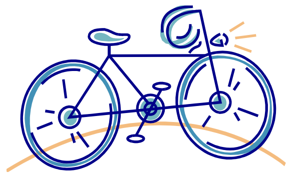
Day 21

Day 22

Day 23

Day 24

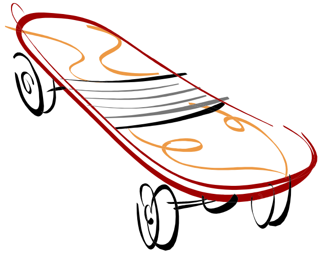
Now you have completed the sixth week of training and deserve a reward.
Reward week 6:



Training week 7

Now the last week of training begins. You have almost finished the training!

Day 28



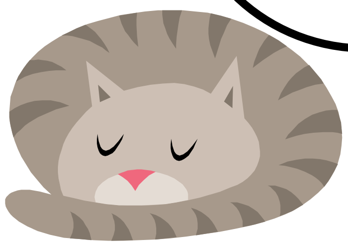
Day 26

Day 27

Now you have finished your last week of training and really deserve a reward!

Reward week 7:

Day 25



Congratulations!

Your training is now complete!

APPENDIX H: COMPLETED STAFF TRAINING SCHEDULES

TRAINING SCHEDULE

Condition 1- Computerised Working Memory Training

RESPONSIBLE COACH: Class Teacher (CT) Author (A)

WEEK 1

Day	Date	Time	Coach	Comments
Mon	20.04.15	9.15-10 10-10:45	A&CT	Pupils in both groups all settled in quite well. Engaged by avatars and their voices. Excited by treasure map. Logbooks done.
Tues	21.04.15	9:30-10 10-10:45	A & CT	Stopped Group 1 5 minutes earlier – unsure if Group 2 would have enough time. All had ok. Logbooks done- large table in middle is good place for logbooks not to be overlooked.
Thurs	23.04.15	9:15-10 10-10:45	A & CT	All started quickly. 1 PC not working so logged child onto other PC. Checking all understood what to do. 1 pupil absent. Logbooks done.
Fri	24.04.15	9:30- 10:15 10:15-11	A & CT	Few children commented on enjoying treasure map as it makes clear what they have to do. Comparing their maps. Showing others the game they were on, as working at different paces. Game prevents some rushing ahead as 1 session per day. Selected class rewards after logbooks.

WEEK 2

Day	Date	Time	Coach	Comments
Mon	27.04.15	9:15- 10:10 10:15-11	A&CT	Internet connection inconsistent – logging several children off and on across groups. 1 boy annoying other boys. R sat beside him but continued to fidget. Tried to interact with him, pointing to features of game which helped settle him. Try movement breaks. Logbooks done.
Tues	28.04.15	9:15-10 10-10:45	A &CT	Children settling very well. Girls working very well. Some boys beginning to get too loud – talking about the game! Ask boy from yesterday (ID:1) to take a message to CT as movement break. I waited at his seat for him coming back. Settled a bit better for time. He wanted to chat to R about his Playstation. We talked about all sound effects of this game.
Thurs	30.04.15	9:15-10 10-10:45	CT	ID 1 absent- appt with CMO. Children working through treasure map consistently. Some able to decorate spaceship when reached end of map. CT had to speak to some boys about noise levels- excitement about different games. Competitive chatter. Logbooks done.
Fri	01.05.15	9:15-10 10-10:45	CT	Pupil absent- away for several weeks to Poland. ID 1- completed treasure map very quickly. Observe next week. Class rewards given. Logbooks done.

WEEK 3

Day	Date	Time	Coach	Comments
Tues	05.05.15	9:15-10 10-10:45	CT	ID 1 observed – unable to notice how he is getting through treasure map so quickly today. Continue to observe more closely tomorrow. 2 pupils absent. Logbooks done.
Wed	06.05.15	9:15-10 10-10:45	CT	ID 1 late today so missed session. All others in group needed some reassurance to complete all trials in a game, pointed out traffic lights at bottom of screen to let them see how many chances they have in a game to earn the jewels.
Thurs	07.05.15	9:30-10:15 10:30-11:15	CT	ID 1 out seat a lot- wanting to help others. He did not finish treasure map. He said "game was for babies." Logbooks done.
Fri	08.05.15	9:15-10 10-10:45	A&CT	All good today. ID 1 more settled and reached end of treasure map as I sat beside him. Was happier he completed today. Logbooks done for most, a few forgot and as they rushed back to class to call pupil from Group 2.

WEEK 4

Day	Date	Time	Coach	Comments
Mon	11.05.15	9:15-10 10-10:45	A&CT	Groups becoming more independent with routine & navigating games. Fewer forgetting logbook. ID 1 and ID 16 not getting along – consider swapping group. ID 1 finished very quickly- he appears to be pressing and holding return key to get through all trials of a game. Couple of girls enjoyed "cute avatar voices" and liked music when treasure map on the screen at the start.
Tues	12.05.15	-	-	No training - CT at CPD
Wed	13.05.15	9:15-10 10-10:45	CT	Session went to plan! All children were very engaged and focused getting to end of the treasure map today. ID 1 absent – apt at paediatrician
Thurs	14.05.15	9:15-10 10-10:45	CT	Able to make rounds – some struggled as some pictures missing from screen- magician's table game. Children to guess missing items. This happened to several. 2 pupils absent. ID 1 and ID 16 will be swapped groups as have fallen out in yard. Sat with ID 1 and ID 16 today to observe. Logbooks done for all but 1 who rushed out to get to assembly.
Fri	15.05.15	9:15-10 10-10:45	CT	All went well today. Boys now in different groups. Swapped ID 1 with a boy making excellent progress from Group 2. ID 1 following me around asking for help. Sat with him for a time and asked to carry on. Progress slowed up, said bored & making errors. Logbooks done- with reminder for a few. Class rewards identified.

WEEK 5

Day	Date	Time	Coach	Comments
Mon	18.05.15	9:15-10 10-10:45	CT	Pupil returned from Poland. 2 pupils asking if they can stay a bit longer to help others. R asked if they would like to come back to logoff the PCs afterwards instead. Logbooks done.
Tues	19.05.15	9:15-10 10-10:45	CT	1 PC not working, so had to add pupil onto Group 2. Some pictures missing from village square game which annoyed some as they did not earn any points. Many enjoying reaching end of treasure map and decorating spaceship.

Wed	20.05.15	9:15-10 10-10:45	CT	1 pupils absent. Session went well – no technical problems and logbooks done.
Thurs	21.05.15	9:15-10 10-10:45	CT	2 pupils absent. All completed treasure map.
Fri	22.05.15	-	-	School holiday

WEEK 6

Day	Date	Time	Coach	Comments
Mon	25.05.15	-	-	School holiday
Tues	26.05.15	9:15-10 10-10:45	CT	1 pupil absent. A couple of children saying programme helps them notice when things change and that they feel more confident using computers. Logbooks done.
Wed	27.05.15	9:15-10 10-10:45	CT / x2 P7 helpers	Sports Day, but programme went ahead.
Thurs	28.05.15	9:15-10 10-10:45	CT	1 pupil absent. All went very smoothly today. Boys a bit loud calling out who is further on in the treasure map and logbooks. 1 pupils asked if he could stay and do his work on the computer as he prefers it to writing. He said programme has helped him to remember more things in literacy because he can remember what words look like more.
Fri	29.05.15	9:15-10 10-10:45	CT	All ok today. Pupils getting excited about the logbooks and reaching end. Class rewards identified and shared. Shame about amount of absences- not uncommon. Those who were there said the programme has helped them to remember what they are told.

WEEK 7

Day	Date	Time	Coach	Comments
Mon	01.06.15	9-9:45 10-10:45 (earlier - Summer Tea)	CT	Children excited because Tea is on this morning. Keen to finish many reached treasure map. Progress excellent from week 1. All earning lots of points. Logbooks done later this afternoon.
Tues	02.06.15	9:15-10 10-10:45	CT	1 absent. Session ok. Some children asking if they can continue with the training next year and others asking if whole school can use it! They said it has helped with sums and work on their own
Thurs	04.06.15	9:15-10 10-10:45	CT	Logbooks are centre of attention today! Excitement about tomorrow. Many children saying programme has helped them remember things at school.
Fri	05.06.15	9:15-10 10-10:45	A & CT	Final session. Log books completed and coloured in by a few. Certificates presented individually to children. All very happy. Most asking to continue.

Note: 28/28 training sessions completed. All sessions durations 45 mins, only 1 session cut short by 15 mins.

Spacing pattern– sessions delivered daily with typical 3-day spacing (one day + weekend). One Bank holiday = 4-day gap.

COMPLETED STAFF TRAINING SCHEDULE

Condition 2- Computerised Numeracy Condition

RESPONSIBLE COACH: Class Teacher (CT) Author (A)

WEEK 1

Day	Date	Time	Coach	Comments
Tues	21.04.15	1-1:45 1:45-2:30 2:30-3:15	A & CT	Children using iPads received slightly longer training time as quicker and easier to log in compared to PCs. Group 2 less time today as Group 1 more difficult to settle - Group 1 clearly less confident with IT compared to Group 2 and 3. More support needed for Gp1IT skills. Logbook done.
Wed	22.04.15	-	-	Session cancelled as CT absent
Thurs	23.04.15	1-1:30 1:30-2:15 2:20- 3:05	A &CT	2 PCs not working -used iPads – had to fetch key from clerical team downstairs- ate into training time. Reminded children to update logbooks at end. 1 child absent.
Fri	24.04.15	1-1:30 1:30-2:15 2:20- 3:05	A & CT	All children enjoying reward time at end of training session. A few selected it early but asked to return to main games, which they did. R selected weekly class rewards with CT. Logbooks done. 2 children absent.

WEEK 2

Day	Date	Time	Coach	Comments
Tues	28.04.15	1-1:45 1:45-2:30 2:30-3:15	A & CT	R supported pupils with log-in and logbooks. CT sat with a few children from Gp1, Gp2 and Gp3 to help navigate games selection.
Wed	29.04.15	“	CT	Internet connection inconsistent. Some children’s machines needed to be reconnected several times= less training time. Logbooks done.
Thurs	30.04.15	-	-	CT Appt- no pupils trained
Fri	01.05.15	1-1:45 1:45-2:30 2:30-3:15	A & CT	Children noting difficulty remembering what games they had tried. Too much choice perhaps? Leaves some less keen. Observed some children select different games midway through. Games are incremental so this may cause problems- check with R. Class rewards given.

WEEK 3

Day	Date	Time	Coach	Comments
Tues	05.05.15	1-1:45 1:45-2:30 2:30-3:15	A &CT	R sat between pairs to encourage them to complete chosen game before moving on in incremental order shown on screen. Beyond selecting pupil’s age when setting up accounts, no mechanism for limiting choice or ensuring incremental games are completed before moving to next. Stopped training 5 mins early for each group to reinforce finishing games before moving to next. Logbooks completed for 2days.
Wed	06.05.15	“	A&CT	All groups seemed engaged today and enjoying reward games. 1 pupil absent. No time for logbooks.
Thurs	07.05.15	-	-	No training today- Internet project in IT suite
Fri	08.05.15	“	A & CT	CT finding 3 groups difficult- late pregnancy. R agreed to support where possible. Logbooks done

WEEK 4

Day	Date	Time	Coach	Comments
Tues	12.05.15	"	A &CT	Coordination of groups easier with 2 of us, less rushing at end of group sessions. Extra person to ensure logbooks not forgotten. Groups managed better with equal time for training. Few pupils losing interest towards end of session today. Sit next to them tomorrow. 1 pupil absent.
Wed	13.05.15	"	CT	R sitting beside pupils who lost interest yesterday. 2 of 3 more engaged. Said game too difficult. 1 pupil needed short breaks & some help to make selection – slower with mouse. Logbooks done.
Thurs	14.05.15	"	A & CT	Continued with short breaks for 1 pupil. Regular rounds to check selecting games from same category. 1 child lost interest when lost reward points. Said they couldn't earn any more points as game too difficult. Sat with them until end of session. Logbook done.
Fri	15.05.15	"	A&CT	Ran smoothly today. Pupils in routine of coming to their designated PC, logging in and selecting games. Still some forget what game they played last. Logbooks remembered by many. Class rewards identified by R, shared with CT.

WEEK 5

Day	Date	Time	Coach	Comments
Tues	19.05.15	"	CT	Internet inconsistent. 3/4 unable to hear narrators for different games. Speakers checked.... asked janitor to check after session. Logbook done.
Wed	20.05.15	"	A	Narrator problem yesterday to do with speakers, Speakers playing up today again. Reported to IT desk by janitor. Few child saying games with avatars and clock too difficult. Logbooks done.
Thurs	21.05.15	"	A	Used iPads for few pupils as speakers being checked by IT. Logbooks done by pupils independently again. CT selected class rewards.
Fri	22.05.15	-	-	School holiday

WEEK 6

Day	Date	Time	Coach	Comments
Mon	25.05.15	-	-	School holiday
Tues	26.05.15	1:30-2 2-2:30 2:30-3:05	CT	Shorter training session for all groups as late getting to IT suite. Continued with iPads for some, as last week. Many enjoying reward games and spending points. Few children struggle with number and they seem to have fewer points which meant they have limited reward games. Logbooks done.
Wed	27.05.15	1-1:45 1:45-2:30 2:30-3:15	CT	All went smoothly using PCs and iPads. R sitting between pairs encouraging navigation through games selection. Few boys rushing ahead and selecting games too difficult. Continue to rein back tomorrow. Logbooks done, several commenting on their own maths progress looking at their reward points. Proud of logbooks.
Fri	29.05.15	"	A & CT	Pupils enjoying progress visible from logbooks and showing R. Boys from yesterday observed, selected next games with some support. 2 pupils chatter about reward games and at each others' avatars. Class rewards identified and shared.

WEEK 7

Day	Date	Time	Coach	Comments
Mon	01.06.15	“	A & CT	Session started on time. Spent some time with small group who were unsure how to move onto next block of sessions on subtraction. Logbooks done with class.
Tues	02.06.15	“	CT	All session went well. More confident to try next games.
Wed	03.06.15	-	-	Sports Day
Thurs	04.06.15	“	A & CT	Sessions well attended. Growing confidence to select new games, less jumping forward. Most enjoying reward games, those struggling to earn points less enthused. Only a few children chatting about rewards. Logbook done.
Fri	05.06.15	“	A	Final session. Logbooks completed and certificates presented. Most appear pleased with progress. Some asking to continue – school providing details to parents about using programme at home.

Note: 23/28 training session completed. 1 extra training day delivered. Unable to offer any additional training days to complete 28 days training as IT suite now booked in afternoons for P7 transition reports.

All sessions durations 45 mins, with 3 sessions cut short by 15 mins each (total of 45 mins lost).

Spacing pattern– sessions delivered daily with typical 3-day spacing (one day + weekend). One Bank holiday = 4-day gap

APPENDIX I: COMPLETED STAFF IMPACT QUESTIONNIARES

WM Condition

Developing working memory and numeracy skills in primary-aged school pupils by computerised training programmes: the effectiveness of adaptive multi-domain working memory training

The staff questionnaire is informed by learning from Implementation Science research and incorporates the five main stages of successful implementation (Kelly & Perkins, 2012). These stages have prompted comprehensive questions that evaluate the process and outcomes of the computerised programmes. These stages include:

- Exploration
- Installation
- Initial Implementation
- Full Implementation
- Programme Sustainability

The questionnaire is also informed by a programme outcome chart as suggested by Langmeyer (2008) to provide a logical map of how the questionnaire evaluates outcomes.

The programme outcome chart is shown below.

Program Outcome Chart for:

Developing working memory and numeracy skills in primary-aged school pupils: Evaluating the effectiveness of computerised training programmes

OUTCOMES		
	Short-term (Reactions / Knowledge)	Did pupils realise working memory is important? Did pupils learn the benefits of developing their working memory? To what extent has the computerised training programme increased your knowledge and awareness of the role of working memory in pupils' learning? Did all pupils participate in the computerised training programme?
	Intermediate (Behaviour)	Has the programme led to any self-directed changes in your practice? Are you aware of any unintended consequences for you from being involved in the project? Has the programme led to any self-directed change in your pupils? Are you aware of any unintended consequences for pupils from accessing the programme?
	Longer-term	Do you think the programme improved children's working memory? What components of the programme, if any, have contributed to improving children's working memory? What, if anything, have you observed to suggest pupils' working memory has improved? Please provide examples of any improvements in working memory.

(Adapted from Langmeyer, 2008)

Developing working memory and numeracy skills in primary-aged school pupils by computerised training programmes: the effectiveness of adaptive multi-domain working memory training

Staff Questionnaire

School: Condition 1 – Computerised WM Training

We are looking to evaluate your experiences of using (insert computerised training programme) with pupils in your class.

The questionnaire is a useful way of gathering information to plan future interventions for pupils in X Council.

Some questions ask you to rate your response with a *circle* using the scale below:

1	2	3	4	5
Strongly disagree	**Disagree**	**Undecided**	**Agree**	**Strongly agree**

Other questions provide space for you to comment.

---

1. How important is the need to focus on developing pupils' working memory in your class?

1 2 3 4 **5**

2. The computerised training programme used minimal resources, such as staff time.

1 2 3 **4** 5

3. Did you possess the necessary skills and necessary coaching given to help you deliver the computerised programme?

1 2 3 4 **5**

4. Does the benefit of the computerised training programme exceed the cost of resources?

1 2 3 4 **5**

5. Pupils accessed key components of the computerised programme as outlined in the instruction manual.

1 2 3 4 **5**

6. Did pupils access the computerised training programme 4-5 sessions per week for 30-45 minutes per session?

1 2 3 4 **<u>5</u>**

7. Please comment on what changes, if any, you made to how the computerised training programme was delivered?

Rewards were set up for the class at the end of each week of training. It was not practical to give individual rewards to each child in the class, which I know the training manual suggests. The manual also recommends involving families in designing the reward system i.e. trip to the park on a Saturday etc. That would be a none-starter with some of our families because many families struggle with family time or routines, and others manage with this well, so it was decided that we take responsibility for rewards here.

The hand-over facilitating sessions was a more gradual process, which was very helpful, and happened naturally. The manual did not actually say that it should be done that way, the expectation was that I would facilitate alone from the beginning. This was more helpful to me and made me more confident and comfortable facilitating on my own eventually.

8. Was delivery of the computerised training programme well-organised and stable over the 7 weeks?

1 2 3 4 **<u>5</u>**

9. Please comment on the intensity of the computerised training programme, taking into account any relevant resource or logistical considerations.

Completing the training schedule was helpful to ensure the number of sessions per week were monitored and delivered as per the manual. The training schedule also let me see how children were developing as they received more training over the weeks. Also, that individual children's needs were addressed over the 7 weeks to maximise what they took away from the training. Booking the PC room for the 7 weeks was vital to avoid potential disruption by other classes and it meant pupils got used to the routine of the time the sessions would take place. You could see how the children were developing as their time on the training cumulated. One PC was unable to be fixed and it would have been helpful to have had a back-up device so that the child did not have to move from their initial allocated PC.

10. Did the computerised training programme reach a sufficient number of pupils in your class?

1 2 3 4 **<u>5</u>**

11. Please reflect on your perceptions of the pupils' experiences using the computerised training programme.

Most if not all regularly looked forward to the sessions. They would ask about going often enough. They particularly enjoyed the simple and structured way programme was, and surprised me with their independence and ability to work on tasks for a significant period of time every session. One or two of the boys were very competitive, which did not take away any benefits, but showed their commitment to getting the spaceship finished and log book completed. It was good to see them engaged in something so strongly. Some of the group wanted the programme to be used in class when we were doing literacy and numeracy work as they felt it helped them to achieve more in those areas. We will see.

12. Should the computerised training programme be used with other classes in the future?

1 2 3 4 **5**

13. Was the computerised training programme delivered in a quiet place in school?

1 2 3 4 **5**

14. In your experience was it practically possible to complete the training schedule and access the management system of the computerised programme to collect and measure pupils' performance and engagement?

1 2 3 4 **5**

15. Do you think support from the Coach throughout the project was effective?

1 2 3 4 **5**

16. What support(s) from the Coach did you find most helpful?

The gradual withdrawal of facilitating each session. Support to complete the training schedule and what to share and observe. Access to the management system was useful to track what pupils were doing and how they were doing.

17. All pupils in the class participated in the computerised training programme.

1 2 3 **4** 5

18. Do most pupils now realise working memory is important?

1 2 3 4 **5**

19. Have most pupils learned the benefits of developing their working memory?

1 2 3 4 **5**

20. Do you think the computerised training programme has improved children's working memory?

1 2 3 **4** 5

21. What components of the computerised training programme, if any, have contributed to improving children's working memory?

The programme was well co-ordinated in school and I think it worked because of that and so as the time on the programme increased, their skills developed too. The programme graphics and main choice board were appealing because it was easy to understand, which helped them become confident and settled to learn. Games were motivating because of the animations and character voices, which helped children engage. The activities in the games were very good and many were what the children experience, like remembering what they saw, its colour and size, from a list of items; listening to recall different sounds etc; remembering where items have been placed. These are all tasks they do every day in class and at home. The programme put real skills into situations that were fun and rewarding. The rewards kept them all keen!

22. What, if anything, have you observed to suggest pupils' working memory has improved as a result of the computerised training programme?

Please provide examples.

During the programme many children were able to listen more carefully to what I was saying and complete tasks or instruction more accurately. Many seemed to understand how working memory works in the classroom, like telling each other and me when working memory is being used in particular tasks. During literacy and numeracy some children seemed to be so much more "switched on" either they were not so distracted, or just ready to learn. They had more ideas and answered more in class. In maths they were able to picture things in their mind more, like during the symmetry work and answering more accurately during mental maths activities. A few children were more confident to use their number squares and number lines whereas before they totally refused, they now saw that it helped their working memory.

23. Have you noted any improvements in pupils' attainment / learning?

1 2 3 **4** 5

24. Please circle which, if any, curriculum areas you have noted pupil improvements.

<u>Health & Wellbeing</u> **<u>Literacy</u>** **<u>Expressive arts</u>** **<u>Numeracy</u>** Religious & Moral Education **<u>Sciences</u>** Technologies Social studies

25. Please comment on any other areas of general improvement you have noted in pupils. *A few seem less distractible in class, but I'm not sure if this is just them maturing. One boy had a traumatic start to life, and he is able to complete tasks now whereas before the programme, he could not sit for even 10 minutes. There are less problems in class.*

26. The computerised training programme has led to self-directed change in pupils.

1 2 3 **<u>4</u>** 5

27. Are you aware of any unintended consequences for pupils from accessing the computerised training programme?
Many of the class are more independent to start and finish work. They are reaching finisher tasks now which is good, which didn't happen before. They also seem to have enjoyed the smaller group arrangement which has built friendships and they help each other more which is so nice to see.

28. The project has increased my knowledge and awareness of the role of working memory in pupils' learning.

1 2 3 4 **<u>5</u>**

29. The project has led to self-directed changes in my practice.

1 2 3 4 **<u>5</u>**

30. Are you aware of any unintended consequences for you from being involved in the programme?
I thought the programme would help just the pupils, but it has reminded me to be more careful about how I deliver my lessons and to make sure I don't lose sight of the fact that working memory has a limited capacity that is involved in everything we do in the classroom. So I now try even harder to make learning opportunities multi-sensory, although I won't be able to compete with the software!

Thank you for your continued support and time

Sharon Brown

Numeracy Condition

Developing working memory and numeracy skills in primary-aged school pupils by computerised training programmes: the effectiveness of adaptive multi-domain working memory training

The staff questionnaire is informed by learning from Implementation Science research and incorporates the five main stages of successful implementation (Kelly & Perkins, 2012). These stages have prompted comprehensive questions that evaluate the process and outcomes of the computerised programmes. These stages include:

- Exploration
- Installation
- Initial Implementation
- Full Implementation
- Programme Sustainability

The questionnaire is also informed by a programme outcome chart as suggested by Langmeyer (2008) to provide a logical map of how the questionnaire evaluates outcomes.

The programme outcome chart is shown below.

Program Outcome Chart for:

Developing working memory and numeracy skills in primary-aged school pupils: Evaluating the effectiveness of computerised training programmes

OUTCOMES	Outcome level	Questions
	Short-term (Reactions / Knowledge)	Did pupils realise working memory or numeracy is important? Did pupils learn the benefits of developing their working memory or numeracy? To what extent has the computerised training programme increased your knowledge and awareness of the role of working memory in pupils' numeracy? Did all pupils participate in the computerised training programme?
	Intermediate (Behaviour)	Has the programme led to any self-directed changes in your practice? Are you aware of any unintended consequences for you from being involved in the project? Has the programme led to any self-directed change in your pupils? Are you aware of any unintended consequences for pupils from accessing the programme?
	Longer-term	Do you think the programme improved children's working memory or numeracy? What components of the programme, if any, have contributed to improving children's working memory or numeracy? What, if anything, have you observed to suggest pupils' working memory or numeracy has improved? Please provide examples of any improvements in working memory or numeracy.

(Adapted from Langmeyer, 2008)

Developing working memory and numeracy skills in primary-aged school pupils by computerised training programmes: the effectiveness of adaptive multi-domain working memory training

Staff Questionnaire

School: Condition 2- Computerised Numeracy training

We are looking to evaluate your experiences of using (insert computerised training programme) with pupils in your class.

The questionnaire is a useful way of gathering information to plan future interventions for pupils in X Council.

Some questions ask you to rate your response with a *circle* using the scale below:

1	2	3	4	5
Strongly disagree	**Disagree**	**Undecided**	**Agree**	**Strongly agree**

Other questions provide space for you to comment.

1**.** How important is the need to focus on developing pupils' working memory in your class?

1 2 3 4 **5**

2. The computerised training programme used minimal resources, such as staff time.

1 **2** 3 4 5

3. Did you possess the necessary skills and necessary coaching given to help you deliver the computerised programme?

1 2 3 4 **5**

4. Does the benefit of the computerised training programme exceed the cost of resources?

1 2 **3** 4
5

5. Pupils accessed key components of the computerised programme as outlined in the instruction manual.

1 2 3 **4** 5

6. Did pupils access the computerised training programme 4-5 sessions per week for 30-45 minutes per session?

1 2 3 **4** 5

7. Please comment on what changes, if any, you made to how the computerised training programme was delivered?

It was not possible for me to facilitate the groups on my own for the duration of the project although that was what was agreed. The sessions were mainly supported with the Author or by the Author alone. So the biggest change was that pupils didn't receive the full training time they were supposed to, and each session was affected by IT problems mainly. The weekly rewards were provided in school for the class as it was not possible to give individual rewards for each pupil.

8. Was delivery of the computerised training programme well-organised and stable over the 7 weeks?

1 2 **3** 4 5

9. Please comment on the intensity of the computerised training programme, taking into account any relevant resource or logistical considerations.

Sessions took place as regularly throughout the project as possible. Unfortunately, a few sessions were less well-organised than I would have liked because I was unable to manage 3 groups on my own, therefore some sessions were rescheduled or missed which meant they didn't have the full training time they were supposed to across the 7 weeks. Having regular access to the iPads could have reduced the number of groups to 2, but access to the iPads was not reliable either; these could not be booked in advance, as was done for the IT Suite. Several of the desktops in the IT suite were not working or broke during the project which added to problems and wasted a lot of time during most sessions.

10. Did the computerised training programme reach a sufficient number of pupils in your class?

1 2 3 **4** 5

11. Please reflect on your perceptions of the pupils' experiences using the computerised training programme.

A few pupils enjoyed the experience and so the school has set up home access to Study Ladder so pupils can now do homework using it. Many pupils found it difficult to keep track of the games they played between sessions, as there was no main screen that they could see progress. This resulted in many pupils not really committing to the tasks as they could only gauge their progress from points earned.

Most enjoyed the experience using the computers to do number tasks rather than working in jotters! I think may lost interest because of the lost time from many sessions, either because of IT issues or organisation problems.

12. Should the computerised training programme be used with other classes in the future?

1 2 **3** 4 5

13. Was the computerised training programme delivered in a quiet place in school?

1 2 3 4 **5**

14. In your experience was it practically possible to complete the training schedule and access the management system of the computerised programme to collect and measure pupils' performance and engagement?

1 2 **3** 4 5

15. Do you think support from the Coach throughout the project was effective?

1 2 3 4 **5**

16. What support(s) from the Coach did you find most helpful?

Explaining how the programme worked and its limits. Facilitating many sessions to ensure sessions were maintained for children and they access the opportunity as regularly as was possible. Managing more challenging children through careful organisation of groupings. Support to complete training schedule.

17. All pupils in the class participated in the computerised training programme.

1 2 3 **4** 5

18. Do most pupils now realise working memory is important?

1 2 **3** 4 5

19. Have most pupils learned the benefits of developing their working memory?

1 2 **3** 4 5

20. Do you think the computerised training programme has improved children's working memory?

1 2 **3** 4 5

21. What components of the computerised training programme, if any, have contributed to improving children's working memory?

The games used maths problems that familiar to work covered in their core programme and textbooks. So they had to try to remember and use their memory of taught concepts to complete games. The games required children to use their working memory to recall number bonds, multiplication facts and to decipher what was required in each game.

22. What, if anything, have you observed to suggest pupils' working memory has improved as a result of the computerised training programme?

Please provide examples.

Some pupils seem to be more confident with maths than before the programme, and perhaps that's because they are remembering taught concepts more accurately. They have certainly had more practise with the programme and their recall of some number facts / times tables improved.

23. Have you noted any improvements in pupils' attainment/learning?

1 2 3 **4** 5

24. Please circle which, if any, curriculum areas you have noted pupil improvements.

Health & Wellbeing Literacy Expressive arts
Numeracy Religious & Moral Education Sciences
Technologies Social studies

25. Please comment on any other areas of general improvement you have noted in pupils.

Many of the children's IT skills have developed as a result of taking part in the project. I was surprised hoe a few really struggled to use the mouse or type in a password. They have gotten so much more fluent with that and more capable of using the computer and with greater independence.

26. The computerised training programme has led to self-directed change in pupils.

1 2 3 **4** 5

27. Are you aware of any unintended consequences for pupils from accessing the computerised training programme?
None

28. The project has increased my knowledge and awareness of the role of working memory in pupils' learning.

1 2 3 **4** 5

29. The project has led to self-directed changes in my practice.

1 2 **<u>3</u>** 4 5

30. Are you aware of any unintended consequences for you from being involved in the programme?
I will try to incorporate ICT into the numeracy curriculum in future.

Thank you for your continued support and time

Sharon Brown

LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

Abbreviation - Definition

ASN- Additional Support Needs

CfE- Curriculum for Excellence

CWMT- CogMed © computerised working memory training programme

DSB- Digit Span Backwards task

DSF- Digit Span Forwards task

EF- Executive function(s)

EP- Educational Psychologist

FR- Fluid reasoning

HMiE- Her Majesty's Inspectorate of Education

MR- Matrix reasoning Task

N – Total number of participants in sample

n – Number of participants in subsample

ns- Non-significant effect ($p > .05$)

PCA- Principal Component Analysis

RCT- Randomised control trial

RT- Response time

SES- Standardised effect size

SEM- Standard error of measurement

STM- Short-term memory

T1- time point 1, or pre-test

T2- time point 2, or post-test

TS- Total score

WISC-IV- Wechsler Intelligence Scale for Children 4th edition

WM- working memory

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