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I certify that all material in this thesis which is not my own work has been identified and that any material that has previously been submitted and approved for the reward of a degree by this or any other University has been acknowledged.

Abstract

Working memory (WM) has neuroplasticity and is important for learning. Secondary school students underachieve in KS3 Science due to having a weaker WM. Domain specific activities to develop WM may increase WM and hence, increase domain specific attainment in students. In this study, Science specific activities are used that were created with the aim to develop WM. A cohort of 171 Year 7 (11-12 years) students were placed into six teaching classes for starting secondary school as part of normal school protocol. The classes were randomly assigned to an active group (N=86) or a control group (N=85). For one and a half academic years the active group had three Science lessons a week which included Science specific activities to develop WM. The control group had three Science lessons delivered with no intervention. Students' WM was measured pre- and post-intervention using a WM assessment called Lucid Recall. Throughout the study students completed a range of Science assessments and student questionnaires as well as interviews. There was no difference between the active and control group's WM or Science attainment. However, the findings do indicate that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. Quantitative data findings show there are significant correlations between WM and Science attainment in the active group that were absent in the control group; a regression analysis of the post-test WM assessment and End of Year report attainment showed a summative value of 0.234. Data from student questionnaires and interviews support this demonstrating that, these conceptual links (a correlation) in cognition between WM and the active student's knowledge and understanding of Science may also be related to changes in the active student's perception of memory, learning Science and metacognition.

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Abbreviations

CE	Central Executive
CPD	Career Professional Development
CtG	Closing the Gap
DfE	The Department for Education
EEF	Education Endowment Foundation
EF	Executive Function
FSM	Free school meals
G&T	Gifted and Talent students
Gc	Crystallised intelligence
Gf	Fluid Intelligence
LTM	Long Term Memory
PoS	Programme of study
PP	Pupil Premium Student
PPA	Planning Preparation and Assessment Time
PPG	Pupil Premium Grant
RQ	Research Question
SEND	Special Educational Needs and Disability
SES	Socio-economic status
SoL	Scheme of learning
STM	Short Term Memory
WM	Working Memory

Chapter One Introduction to the Thesis

1.1 Establishing the aims of the doctorate

Working Memory is important for learning (Dehn, 2008). Students with a weaker WM have lower attainment in school (Alloway & Gathercole, 2009; Gathercole et al., 2004; Packiam Alloway et al., 2010). Working memory has neuroplasticity and can be improved by WM training (Boudreau & Contanza-Smith, 2011; Lohaugen, et al., 2011; Malekpour & Aghababei, 2013; Van der Molen, et al., 2010). Underachievement, in the classroom denies students of life opportunities, perpetuates social injustice and leaves a vacuum of economic want. The aim of this doctorate is to find out if activities to develop working memory developed for KS3 Science lessons, increase WM and hence, increase Science attainment and ultimately the life chances of students. The working memory activities have been placed explicitly into each Year 7 and Year 8 lesson plan outline. If the outcome of the study confirms the link between the activities and an increase in science attainment; then the working memory activities (as an integral part of each lesson plan) could contribute to an increase in national and international Science attainment (Gorard & Huat See, 2009).

1.1.1 Improving Science attainment for all KS3 Students by improving Working Memory

This research doctorate aims to discover if activities to develop working memory that I have developed for KS3 Science lessons increases Science attainment of KS3 students. As a teacher who trained in 2000-2001, in the first three years of their career completed a master's degree in education and in the subsequent 16 years have completed many action research projects, and evidence-based research projects. I have always focused on removing underachievement from the classroom. Researching areas as broad as the underachievement of gifted and talented (G&T) Students, School Curriculum Design and Behaviour Management in the hope of ensuring all students would achieve their maximum potential life. In 2013 I became interested in research linking student underachievement to weak WM. Since 2013 I completed two years of classroom-based action research which has culminated in applying for and consequently undertaking this doctorate; examining if activities to improve working memory (WM) embedded within the lessons of the Science curriculum improve Science attainment for all students of all abilities and backgrounds.

Underachievement in Science attainment is both a national and an international issue (Gorard & Huat See, 2009). There have been many approaches to improving attainment in Science including the CASE initiative (Adey & Shayer, 1993) scientific reasoning (Klahr & Dunbar, 1988) (Halpern, 1998) and the focus of literacy in Science (Kuin Lai, et al., 2014; McDonald, et al., 2011). Internationally, research has indicated that parental involvement, early intervention, teacher interaction and healthy school programmes would be effective strategies in increasing attainment (Banerjee, 2016; Yong Tan, 2019). There has been no wide scale approach to specifically tackle underachievement in Science by addressing and training the WM of students. WM is the mental notepad and Dictaphone for our brains. All the information we see (including pictures, diagrams, and the written word) and all the information we hear, are held temporarily in the WM. This new information is processed and linked to other information in the long-term memory (LTM) and then stored as new information in the LTM (Baddeley, 2014). Hence, there is a wealth of literature that states WM is important for learning (e.g., Dehn, 2008; Alloway & Gathercole, 2009). Teachers often during lessons expect students to be able to hold onto and process many instructions or hold onto a large amount of subject content in one task. In students with a weaker WM this may lead to new information not being processed and hence not stored in LTM leading to poorer attainment (e.g. Dehn, 2008; Fenesi, et al., 2015; Petty, 2009).

The brain has plasticity; so the WM as part of the brain also has neuroplasticity (McNeil, 2009). WM training has been completed in a number of disciplines including physical activity, mindfulness, music, mental arithmetic and computer training.with a wide range of ages (Diamond & Ling, 2016; Chambers et al., 2008; Jha et al., 2010; Lee, et al., 2007; Westerburg & Klinberg, 2007). WM training to improve WM has been conducted with some success in schools (Apter, 2012; Dunning et al., 2013; Fernandez-Molina, et al., 2015; Rueda, et al., 2012; St Clair-Thompson, et al., 2010). There has been limited success in WM training in schools with some near transfer effects and very limited far transfer effects. Hence, teachers are currently advised to differentiate to support students with a weaker WM (Alloway & Gathercole, 2009). However, there are some researchers that think domain specific WM training could have near transfer effects and hence, have a positive impact on attainment (Titz & Karbach, 2014). Peng and Swanson's (2022) domain specific approach to WM training suggested increases in academic attainment with a recommendation for further research in this area (Peng & Swanson, 2022).

This thesis is focused on improving the WM and Science attainment for all. However, there is a vast amount of research that focuses on the Socio-Economic Status attainment gap in Science so it would be remiss of me not to acknowledge the literature in this area and how outcomes of this research may input into this PhD research study. There is evidence to suggest both nationally and internationally that the SES attainment gap is present in Science attainment (e.g., Alivernini & Manganelli, 2015; Banerjee, 2016; Gorard & Huat See, 2009; Hollins, 2016; Yong Tan, 2019). This evidence indicates that students from poor SES underachieve in Science compared to their peers; both at the age of 11 (at the start of KS3) and at the age of 16. This has a knock-on effect to the number of students from low SES backgrounds studying Science at University (Gorard & Huat See, 2009). The report also suggests teaching methods and strategies that may have efficacy in improving Science attainment and hence also in closing the SES gap of science attainment. These include teaching students specifically about control variables, having good literacy in Science and metacognition in Science (Terezinha, et al., 2017). The latter two have been linked to WM and training WM (for example Cornoldi, et al., 2015; Kellogg, 2001).

My aim for this research is to find out the efficacy of the WM activities to develop WM that I have developed to improve WM and hence increase Science attainment. The intention is to improve Science attainment and hence life opportunities and chances for all students. All KS3 students could potentially benefit from the intervention investigated in this PhD study.

1.1.2 The link between Working Memory, Long Term Memory, and Learning in Schools

This doctorate is based on improving all student Science attainment with the use of activities that are designed to develop WM. These activities are undertaken as an integral part of Science lessons within the lesson plans of the Schemes of Learning/Work at the research school. These activities to develop Working Memory (WM) can only be effective if there is a link between WM, Long Term Memory (LTM) and learning.

Current research enables us to see some of the physical parts of the brain that contain the working memory (e.g., temporal cortex, parietal cortex, prefrontal cortex) and long-term memory (e.g., striatum, medial temporal lobe, prefrontal cortex) and how these physical parts of the brain connect with one another (Eriksson, et al., 2015). However, there is still a great deal of research that needs to be done in this area of neuroscience (Eriksson, et al., 2015). Hence, different working memory models exist using different studies and research findings to build a construct that best fits the evidence that is currently available.

Cowan proposed a hierarchical model suggesting that short-term memory is the activated part of the long-term memory (Cowan, 1988). In Engel's model working memory function and capacity are more closely related to the general factor of intelligence (Engle, et al., 1999). Ericsson and Kintsch have suggested that long-term knowledge and acquired skills consider the variability in the working memory capacity (Ericsson & Kinsch, 1995).

Baddeley and Hitch developed a widely accepted theory of working memory in the early 1970s. This model includes the 'phonological loop' and 'audio-visual sketchpad' which bring auditory and visual information from the environment to the 'central executive' which has the role of processing the information. Working memory is the mental note pad people have in their minds where they hold and manipulate information over a short period of time (Baddeley, 2014).

The commonality of all WM models is that they have an ability for a person to take in new information, process this information and stored this in their long-term memory. The model that is used in this doctorate is the widely accepted Baddeley and Hitch Model. Where the 'central executive' part of the construct can take existing stored information from long-term memory (LTM). This stored information is then linked to new information from the phonological loop, audio-visual sketch pad and episodic buffer (Baddeley, 2014). This linking new information to established long-term memories; in a way that enables new information to be processed to build on or contrast with previous information in the long-term memory; allowing learning to take place.

The academic research that links the WM to LTM and hence to learning, has been recognised by Universities for ITE course content and by the governments internationally in shaping their education policy. The link of LTM and learning is supported with evidence from academic research and this has transferred to education policy both national (Unknown, Gov.uk, 2019) and internationally (e.g., Barenberg, et al., 2018; O'Hare, et al., 2017; Roediger & Karpicke, 2006).

The focus of educators within schools both nationally and internationally is driven by government policy. The policy drives the teaching standards. Nationally and internationally teaching performance in the classroom is measured quantitatively using test and exam data (Fiorello, 2020; Grek, 2009). In an increasingly target driven education system nationally (and globally) (Grek, 2009) the need to set annual performance targets drive teacher focus.

Nationally schools are judged by Ofsted using a set of criteria and published (test and exam) data. Internationally there is a similar shift to government using LTM in criteria and quantifying outcomes (Grek, 2009). The Ofsted criteria that schools are currently judged on includes explicit reference to long term memory. There is strong evidence outlined above to suggest that WM is how students place information in the LTM (e.g., Baddeley, 2014; Cowan, 1988; Engle, et al., 1999; Ericsson & Kinsch, 1995). This places the link between WM, LTM and learning firmly at the heart of school improvement.

This can be seen explicitly in Ofsted's new Inspection Framework. *The Quality of Education* is one of the four key judgement areas of Ofsted. Enabling learning to take place where students are committing information to the long-term memory is integral to this area of the inspection. In *The Quality of Education* section there are two areas where the document refers explicitly to students transferring information into their LTM. According to Ofsted “Teachers ensure that pupils embed key concepts in their long-term memory and apply them fluently. The subject curriculum is designed and delivered in a way that allows pupils to transfer key knowledge to long-term memory” (Ofsted, 2019, p. 44)

> “Learning can be defined as an alteration in long-term memory. If nothing has altered in long-term memory, nothing has been learned. However, transfer to long-term memory depends on the rich processes described above. In order to develop understanding, pupils connect new knowledge with existing knowledge.” (Ofsted, 2019, p. 45)

An effective, simple to implement teaching strategy to develop WM, to increase attainment and close the SES attainment gap will be highly sort after by schools. A school-wide roll out of a teaching strategy to develop WM would explicitly demonstrate a school meets Ofsted criteria and educational standards. Moreover, and most importantly this would increase the attainment of their students. Hence, the academic research that shapes national and international education policy places this doctoral research thesis at the heart of whole school improvement globally.

1.1.3 Establishing the research questions

Hence, the aim of this doctorate is to investigate if activities developed to train the WM as part of the KS3 Science curriculum are effective in improving Science attainment. If this is the case this will meet my aim; to increase the attainment of underachievers as well as those students who are attaining highly in Science. As a classroom teacher who is constantly researching different ways to enable underachieving students to fulfil their potential this is an opportunity which could not be missed. The outcomes of the research could have national and international impact delivering an efficient and effective way to increase Science attainment a close the SES attainment gap in science in secondary schools.

A potential intervention that encapsulates these recommendations is the introduction of process-based complex working memory (WM) training embedded within KS3 Science lesson plans.

A review suggests this can have positive effects on academic performance (especially those associated with reading) and seems to be of particular benefit (but not exclusively) to low achieving pupils (Titz and Karbach, 2014). This research proposal is based on discovering if the activities to develop WM that I have developed for KS3 Science lessons increases Science attainment. I have designed these activities with the intention of increasing the working memory capacity of students. I spent the three years prior to starting the PhD conducting action research based on the activities to develop Working Memory and delivering them within a standardised lesson plan outline. This was initially with one class, then with a whole year group. The activities to develop working memory delivered in Science lessons seems to increase attainment in Science.

The importance of WM to learning, the widespread WM overload of students within lessons, alongside many learning disabilities having a WM weakness; juxtaposed with the lack of teacher planning to lessen WM load or differentiate for students with a weak WM may well be leading to a major cause of underachievement of students in Science. The issues of underachievement of students coupled with the link between lower student attainment and weak WM is an area that warrants further investigation as a gap in the research has been identified. There has currently been no research conducted on domain specific WM training using activities to develop WM that are embedded within KS3 Science lessons (see part 3 of literature review). Furthermore, there has been no research conducted into WM training; where the WM training is subject specific to Science or including activities that are delivered by the class teacher as an integral part of each lesson plan within the SOL/W of a Science Department. There is also no research conducted into investigating if WM training may improve student attainment and hence decrease student underachievement in Science.

The goal of this doctorate research is to find out if activities to develop working memory that I have developed for KS3 Science lessons are effective in increasing WM and hence demonstrates efficacy in increasing Science attainment in KS3 students. This leads to the broad research question:

What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?

Which can be separated into five distinct questions.

a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, science?

and learning in Science compared to the control conditions?

e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

1.2 Outline of Doctoral Study

The proposed research will examine the effects of activities to develop working memory that I have developed for KS3 Science lessons on the working memory and science attainment of KS3 students (Year 7 & 8). Permission was sort and granted from a rural Devon Secondary School to carry out the two-year longitudinal study with a cohort of 180 of their students. The study would take place in all the science lessons of those students throughout Year 7 and Year 8 (See Chapter Three Method & Methodology). In order to conform to the ethics surrounding experiments involving school age students two safe guards were put in place. The first was that parents could opt their child out of the research; the second was that the students have to actively opt into the research.

The cohort of students would be divided into two groups the active group and the control group. The active group would experience the activities to develop working memory that I have developed for KS3 Science lessons to develop WM in their Science lessons. The control group would have normal science lessons. The students would all undertake WM testing as a baseline, in the middle and the end of the study. There would be a range of Science attainment measures including Science homework, Science summative tasks and the final reported grade for each year. Students would have interviews and complete questionnaires. The Science teachers, Science teaching assistants and all the school staff would be invited to complete questionnaires.

The difficulties of controlling all the variables in this design are recognised. The most significant barrier to producing valid results from this study is the many influences on the student cohort that cannot be controlled or matched. I implemented the questionnaires in part to maximise the transparency of the study.

1.3 The outline of the thesis

The outline of the thesis will have a summary of what each chapter will include. In Chapter Two I will review the literature. This will be achieved by demonstrating how the national and international research on Baddeley and Hitch Working Memory model and the research completed in its' wake has informed the study context, focus and methodology to both form and hence investigate the research question for this PhD thesis. Furthermore, this literature review will highlight a gap in the research published both nationally and internationally on classroom-based WM training to improve Science attainment in Secondary school students.

In Chapter Three I will review the methodology and method of the research. The methodology will give due consideration to paradigms and justify placing the research within a pragmatic paradigm. The benefits and drawbacks of using mixed methods research will also be discussed in this section. This section will conclude in a detailed method of how the research was conducted.

In Chapter Four the I will review the analysis of the data. The quantitative data was analysed using the statistics software IBM SPSS Version 26. Descriptive statistics were used was used to analyse the following differences between and within the control and the active group. The inferential statistics independent t-tests were conducted to analyse the difference in means between the:

- WM test scores
- Science Attainment Scores

Furthermore, analysis was completed to identify and examine the strength of correlations on the following using inferential statistics tests

- between WM and Science Attainment
- between change in WM and Science Attainment

Supporting this; were the differential statistics that were used to analyse the responses to the student questionnaires and the student interviews. The data collected for transparency of the study also underwent differential statistical analysis. The free response from interviews and questionnaires was collated and quantified in terms of being positive, negative, or informative.

Chapter Five will review the findings of the data analysis and hence the research study. The credence, rigour and validity of the conclusions will be discussed. The issue of WM training will be discussed critically including the differing models of WM being used as there is no definitive understanding of how different parts of the brain interact and combine to form the function of WM. The limited number of studies where WM training interventions have been used in the domain specific to secondary Science education will also be discussed and how this leads to tentative conclusions only being made. Also in the discussion, are the issue that findings reported in the literature are divided on the issue of the efficacy of WM training interventions for near transfer effects, increases in attainment and far transfer effects. The use of qualitative data within the study will also be discussed. This includes the use qualitative data enabling me to investigate the research question on different strata, but also critical examination of my conclusions due to the lack of findings reported in the WM training intervention literature on student perception and metacognition. The impact being the tentativeness of the conclusions due to these factors is also discussed

Finally, the limitations of the research will be discussed. Chapter Six will review the evaluation of the research study. This evaluation pays particular attention to the quantitative data and the specifically to the wording of questions and the range of responses in questionnaires. This chapter will finish with suggestions for further research to investigate the area of WM, learning and attainment.

Chapter Two Literature Review

2.1 Introduction

2.1.1 Aim of this Section

The aim of this section is to be a conventional literature review and will show how the methodology to both form and hence investigate the research question for this PhD thesis. In the English inclusive mainstream education system, it is important to embrace differences including those where students' brains mean they have learning disabilities (Packiam Alloway & Alloway, 2015).

2.1.2 Rationale of Literature Review

The rationale for this literature review has a seven key constructs. These are 1) underachievement in secondary science, 2) WM (definition of WM), 3) WM is necessary for learning to take place, 4) WM can be developed (has neuroplasticity), 5) people who complete specific activities can increase their WM, 6) increasing WM increases (Science) attainment and 7) completing specific activities in the classroom can increase WM and hence increase (Science) attainment.

A weaker WM can lead to underachievement in School; and hence, weak a WM can lead to underachievement in Secondary School Science. For many years, the focus in education has been underachievement of students (e.g., DfE, 2015;14-19 Learning & Skills Bulletin, 2019; Lessof, et al., 2019). This underachievement at school leads to people not fulfilling their personal potential and having limited life opportunities (14-19 Learning & Skills Bulletin, 2019) (Baars, et al., 2019). The underachievement of students at school has an impact nationally both on an economic level and a social level. The underachievement of students has been tacked nationally by the pupil premium (PP) initiative introduced in 2011, and hence the impact of this initiative has dominated the literature on this subject.

However, another contributor to student underachievement is that of students having a weak WM. Although a weak WM has been be linked to learning difficulties such as dyslexia and dyscalculia (Packiam Alloway & Alloway, 2015) some students have a weaker WM and no learning difficulties (Alloway & Gathercole, 2009). Students are not explicitly tested for WM capacity in school so there is no way to know the extent of weak WM on student underachievement. It may be having a significant impact on lack of attainment in schools.

Furthermore, there is a possible link between students who have weak WM and underachievement. There has been a great deal of research into WM as a differentiator of attainment. Students from disadvantaged or poorer backgrounds are more likely to have a learning disability (DfE, 2015). The evidence suggests that students with a learning disability will also have a WM deficit (Packiam Alloway & Alloway, 2015). There is also evidence that tends towards students with the weakest WM having the lowest attainment at school (Gathercole, et al., 2004).

The current support given to students who have learning disabilities is for teachers to differentiate work and to direct teaching assistants (or other support staff) to support a student in a specific way. The information and advice for teachers about students with WM deficits also follows these guidelines (Alloway & Gathercole, 2009). However, there is research that indicates that the brain has plasticity. Some researchers have been investigating the plasticity of WM. The research implies that WM can be trained using activities (many of these activities are on the computer). For example, a study on 7–9-year-olds recorded increases in verbal WM that were still measurable a year after the training (Dunning, et al., 2013). However, there is scant evidence demonstrating near or far transfer effects on other aspects of brain activity (including school attainment). One might conclude that the majority of the WM training programmes just help people get better at the training programmes (e.g., Diamond & Ling, 2016). On the other hand, there is an argument for exploring the neuroplasticity of WM; by using activities to develop the WM of students within a Science lesson and analysing the impact this may have on the Science attainment of students.

2.1.3 Outline of what ideas will be reviewed

This literature review will cover the following areas:

In section 2.2 the methodology of the literature review will be outlined including explanations of how literature was selected using both a systematic and a scattergun approach. Furthermore, there will be an explanation of how the selected literature was useful in developing my theoretical design framework for my research study

In section 2.3 the findings and theory from the literature of the key construct underachievement in Secondary Science are examined and discussed. Due consideration is given to the theories, models, programs, and other classroom activities that have been demonstrated to increase Science attainment. Given that this research is not being conducted in a laboratory any conclusions and findings should be critically considered, including the impact the teaching pedagogical theory, modes, programmes, and other classroom activities that are showing that they increase science attainment that may account for any increase in science attainment as opposed to WM increases being the cause of an increase in attainment. Hence, the literature on increasing Science attainment was reviewed and will inform any critique on positive conclusions in the discussion and findings part of the thesis.

In Section 2.4 the findings and theory from the literature of the key constructs WM and WM is necessary for learning to take place are examined and discussed. Section 2.4 is split into three parts. The second part looks at the different models of WM that I may have used to undertake and shape my research and how WM is integral to learning. The third part justifies the use of the Baddeley and Hitch model of WM within the research and how it is integral for learning.

In Section 2.5 the findings and theory from the literature of the key construct WM is important for learning are examined and discussed. Specifically, in Section 2.5 the literature published on how WM is important in a school setting with school aged students is discussed. In Section 2.6 the findings and theory from the literature of the key construct WM can be developed (has neuroplasticity) are examined and discussed. Specifically in Section 2.6 the national and international research about the plasticity of WM is considered. Following on in Section 2.7 the findings and theory from the literature of the key construct increasing WM increases (Science) attainment are examined and discussed. More specifically literature is discussed about WM being a differentiator of attainment. Establishing the key constructs this within the research and demonstrating that there is as far as I am able to ascertain no research to date has been published; that has been conducted with the aim to improve Science attainment using activities to develop WM.

In Section 2 8 the findings and theory from the literature of the key construct increasing WM increases (Science) attainment are examined and discussed. Including analyses and synthesises of the literature published on WM training with school aged students. In Section 2.9 the findings and theory from the literature of the key construct of completing specific activities in the classroom can increase WM and hence increase (Science) attainment were examined and discussed. This included both national and international literature on WM training within a school setting. This literature is critically examined in Section 2.9. Section 2.10 discusses the outline of the issue of using activities to develop WM, to increase WM and hence increase Science attainment in KS3 students. This section synthesises the theory and findings from the literature of the seven key constructs: These are underachievement in secondary science, WM, WM is necessary for learning to take place, WM can be developed (has neuroplasticity), people who complete specific activities can increase their WM, increasing WM increases (Science) attainment and completing specific activities in the classroom can increase WM and hence increase (Science) attainment. This will include how the findings and theory from the literature of the key constructs developed the formulation of the research questions.

Finally, in Section 2.11 there is a section that proposes the theoretical framework which will be used to answer the research questions and to be able to generalise findings more widely within a secondary school Science education context. This will include how the theory and findings of the literature of the key constructs supports the logical thinking behind and justification the approach to the study and how this enabled the research questions to be researched and answered in the context of the theoretical framework.

2.2 Methodology of literature review

2.2.1 An explanation of how the selected literature was based on a systematic and a scattergun approach

Over the duration of the PhD and in the years preceding this research study I have sort to find relevant literature that would give me an insight into what was Working Memory, can WM be trained (Does WM have plasticity)? How WM is linked to learning, and specifically how it was linked to learning in secondary school Science. Hence, how WM was linked to secondary school and specifically KS3 Science attainment.

After my original action research that led me onto the PhD. When I searched for literature specific to my PhD thesis research questions there were very few articles available (Figures 1, 2, 3) and even fewer available that took a negative stance of training WM for school aged students. This led me to take a scattergun approach to finding relevant literature that would run alongside the formal systematic searches. This took the shape mainly of finding articles that had been referenced in related WM articles. This was a time-consuming process but has enabled me to be confident that for each section of the literature review I have selected and reviewed the literature that has informed and shaped the research study. Furthermore, I have used the literature to justify and demonstrates how this relates to both the Baddeley and Hitch model of WM (Section 2.4.4 p. 63) of this literature review) that I am using and the theoretical research framework (Section 2.11) I have designed to answer my research questions (RQ).

2.2.2 Justifying why the selected literature was useful to answer my research questions

There will be a section at the start of each part that will outline how the literature was selected for that particular section (Appendix A). In addition, there will be a justification of using that literature in the context of using the Baddeley and Hitch WM model (Section 2.4.4 p. 63); this in turn will enable me to justify how the literature will inform and justify the research questions relating to WM training in school aged students, WM training leading to increases in attainment in school aged students and literature published that has previously demonstrated that activities to develop WM have had an impact on student attainment (specifically in secondary school aged students).

2.2.3 Why the selected literature was useful for developing my theoretical framework

The theoretical framework design has been developed using the Baddeley and Hitch Model of WM (Section 2.4.4 p. 63) to gather quantitative and qualitative data to get a full and layered understanding of the impact of students completing WM activities to develop WM in their Science lessons (Section 2.11). The framework will enable me to test if WM activities to develop WM and hence Science attainment; do quantitatively change WM and Science attainment. Furthermore, do these activities qualitatively change KS3 students' perception of their memory, science and learning in Science. In addition to which do these activities and students metacognitive reflection of them qualitatively have an impact on the metacognition of KS3 Students both in science and any far transfer effects of completing the WM activities.

The framework encompasses and embraces the fact that the research is naturalistic and experimental– conducted in the real world with its' many confounding variables making any impact difficult to justify when looking at one layer of the impact of the research. Hence, having a theoretical framework that allows me to research the quantitative and qualitative aspects will give a greater insight into any impact experienced by the active group compared to the control group; by looking at pre- and post-intervention quantitative and qualitative data.

A review of the literature of mixed methods research and the literature of WM training articles supported the development of the quantitative data gathering side. Whereas, a review of the literature for studies based in schools and mixed methods & pragmatic paradigm research informed the shape of the qualitative data gathering. This will be explained and justified in detail in Section 2.11 of the Literature Review.

2.2.4 Methodology to identify published articles for the Literature Review

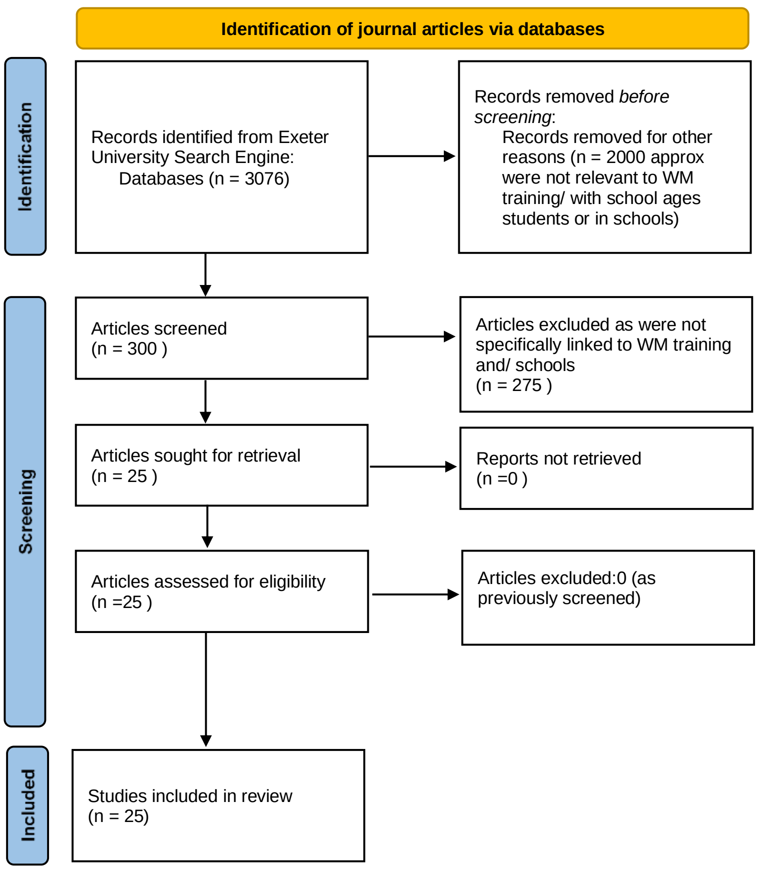
The research for this literature review had a strategic approach; when searching the literature for appropriate articles and studies. The initial search involved using the search engines at The University of Exeter Library using the search parameters of specific key words: working memory, executive function, training, learning, secondary, education, attainment, achievement, school, kindergarten. The key words were used in different permutations. The inclusion criteria were any article published in an English language journal in the year 2000 onwards. The exclusion criteria were any journal not published in English or published before the year 2000. The following data bases accessed through University of Exeter Education library were used in the search: Australian Education Index, British Education Index, E Journals from EBSCO, and Exeter University Library Article Search. I went through the search findings to find articles that were specifically about WM Training and WM Training with children/students or in schools (Figure 1).

Furthermore, as the initial search did not include many relevant journal articles so any papers that had been referenced in previously read papers that were relevant to the literature review using the key words, inclusion and exclusion parameters stated above were also included. The publications were sourced from both The University of Exeter and other Universities to which the researcher has access.

In addition to which as the research study progressed it became apparent that literature that was critiquing WM training research was very sparse, so I had to return to the literature and use synonyms for neuroplasticity in education these were: educational neuroscience, neuroeducation and mind, brain, and education (Figure 2).

Initially considering all literature that had been published that linked to WM training. Then narrowing the parameters further to identify any literature that had WM training of school age children. This literature review will demonstrate that there is a lot of literature published on WM training however only a very small number of published pieces of research investigate how training WM in the classroom may increase attainment.

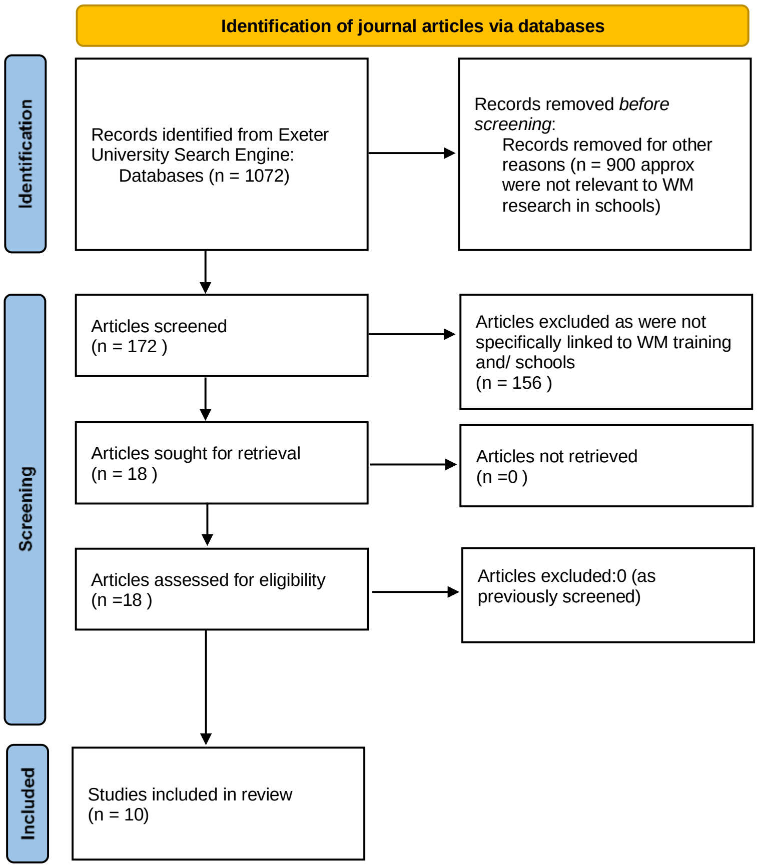
Figure 1 A PRISMA diagram outlining the search process for finding journal articles on Working Memory Training and or in school aged students and in schools



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

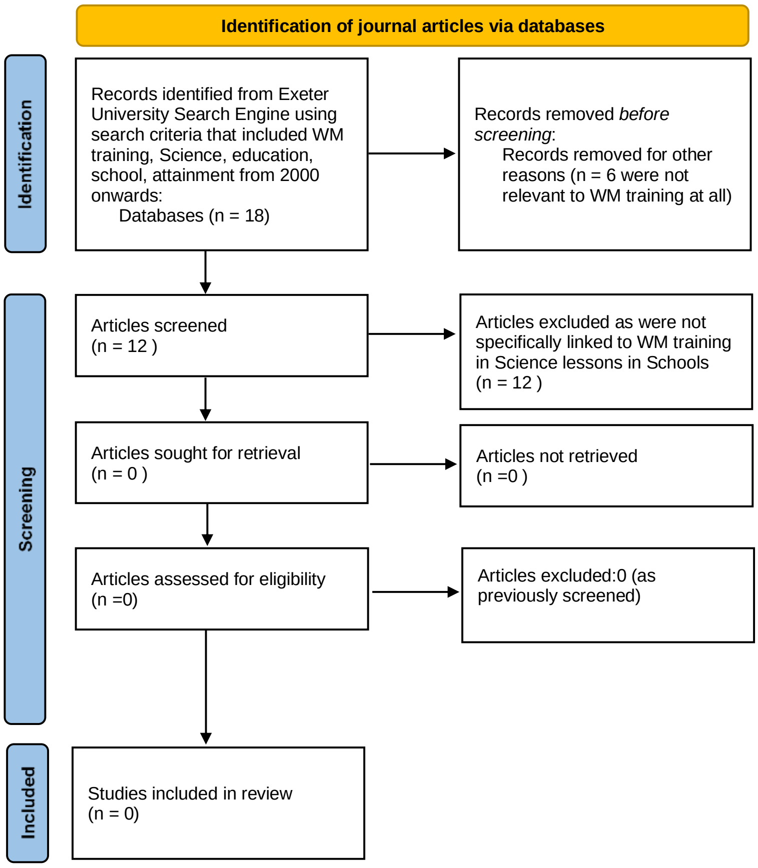
Figure 2 A PRISMA diagram outlining the search process for finding journal articles critiquing education neuroscience, neuroeducation and mind brain education relevant to Working Memory Training and or in school aged students and in schools



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Figure 3 A PRISMA diagram outlining the search process for finding published literature on Working Memory Training in Science lessons in schools



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

2.3 Improving Attainment in Science

2.3.1 Introduction

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 30 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of improving attainment in Science.

2.3.2 Introduction to Improving Attainment in Science

The key construct covered in this section is underachievement in Science; specifically what strategies are available for teachers to employ that will counteract this underachievement. The definition of the key construct underachievement in Secondary Science is a broad term covering students whose attainment does not meet the expected level or grade for their age in Science.

The aim of this Section is to specifically address strategies, programmes and initiatives published in the literature that are related to increasing Science attainment in students; and how these ideas may be used to critique and argue against any positive conclusions made within the discussion section of the thesis about the science subject specific activities that have been designed to develop WM (and hence Science attainment in KS3 students) that this thesis is based upon. Starting with the conflicting pedagogical stances of Piaget and Vygotski and how these impact on Science lessons and hence science attainment and then considering strategies, programmes and initiatives that may increase science attainment.

The following are covered in this Section:

- Pedagogy of Piaget and Vygotski
- Klahr and Dunbars Scientific Discovery through Dual Search Model (SDDS) of Scientific learning
- Whiteboards in Classrooms, Digitial Natives, Learning Styles,
- Self Regulation of Learners, Metacognition, Distributed Practive, Elaborative Interrogation
- Evidence Based Research sources the Education Endowment Foundation and The Learning Scientists and Assessment for Learning
- CASE and Individualised Student Instruction

- Research into other factors that report to demonstrate an increase in WM and hence attainment

At the heart of all good schools, are well run departments, which are staffed with teachers who are passionate about increasing the life choices of students. However, with the constant barrage of new government initiatives it is easy to lose sight of what really makes an impact on the learning of students. The vast majority of Science teachers want to ensure students learn in their lessons and have a good level of attainment in Science. There are many strategies, programmes and initiatives that claim to have an impact on pupil progress and hence, attainment. Some of these strategies, programmes and initiatives appear to be based in educational research or pedagogical cognitive models whereas others do not. This Section of the literature review aims to addressa wide range of these strategies, initiatives and programmes and discusses how they may improve students learning, progress and hence academic attainment within KS3 Science. The efficacy of these can then be juxtaposed against the effectiveness of activities to improve WM (WM training) to increase WM and hence KS3 Science attainment. The aim is to not cover every possible strategy that may be used in Science classrooms but to give a representative range of strategies and programs that Secondary Science teachers may be using to raise attainment. These were chosen from the range of strategies that have been part of the CPD/training over the past 18 years or were chosed to show the diverse range of approaches available.

2.3.3 The pedagogy of Piaget and Vygotsky and how these relate to KS3 Science attainment

At the core of Piaget's cognitive development model is cognitive conflict when the child's experience of the world cannot be explained by schemas they already have. This appears to cause disequilibrium and the child has to go through the assimilation and accommodation to return to the equilibration (McLeod, 2015). This indicates that because students are experiencing cognitive conflict in KS3 Science lessons, this enables cognitive development to take place (McLeod, 2015). Cognitive conflict is an aspect that students meet in many KS3 Science lessons. This cognitive conflict could be causing the acceleration of the development of the students and could account for increased learning in science and rapid progress that can often be observed in the early years of secondary school.

Piaget's research led him to believe that a child's cognitive development occurred in stages (McLeod, 2015) WM research has also demonstrated this (Demetriou, et al., 2014). On the other hand, Piaget's cognitive development theory does not directly link into the WM aspect of this research. However, Piaget and Inhelder's research indicated that the LTM was highly schematic and the STM could have access to the LTM. If the activity completed by the child did not have a schema related directly to it then recall from LTM would be difficult (Piaget & Inhelder, 2015 (first published 1973 in English)). This could be an explanation for new information taking a lot of WM capacity to process and hence learning a completely new KS3 Science topic is more difficult to learn.

The approach of this research doctorate study is the use of science subject specific activities to develop WM to develop the WM of students and hence increase their science attainment. This indicates that the cognition of the students has to improve before the deeper learning can take place. However, Vygotsky in direct contradiction to Piaget believed that children's development was linked to learning. The children learned about the world about them and thus went on to develop their cognition. Piaget's theories claim that the cognitive development has to occur first and then this would lead to learning. Vygotsky's theory has culture and social interaction at its heart. Vygotsky promoted the idea that children in different cultures develop differently and at different rates. Furthermore; he claimed that adults can be a conduit to enable children's cognitive development to occur (McLeod, 2007 updated 2014). At the heart of this theory was the zone of proximal development; this has enabled adults and peers to bridge the gap between the knowledge or skills the children have and those they do not have to complete a task (McLeod, 2007 updated 2014). This is how Vygotsky explains learning taking place. There is some supporting evidence that in a classroom the teacher or peers would be able to bridge the zone of proximal development.

The cognitive conflict of Piaget and the bridging of the zone of proximal development of Vygotsky are both used in Science classrooms in the study school. This knowledge informed the study by ensuring that I included lesson observation, student interviews and student, teacher and teaching assistant questionnaires to be able to give me an insight into the teaching strategies employed with the active and control group and what impact that may have on their attainment that could not explicitly be attributed to WM development.

2.3.4 Klahr and Dunbar's Scientific Discovery through Dual Search and how this relates to KS3 Science attainment. Also included is a discussion of how this model might be better than and also relate to the activities to develop WM (and hence increase Science attainment)

Klahr and Dunbar's SDDS (Scientific Discovery through Dual Search) model states that when faced with a scientific problem, people will either formulate a hypothesis by searching using their prior knowledge or search their observations from experiments. The formulation of one or more hypotheses will lead to individuals conducting experiments and the results of the experiments will be evaluated. This might lead to a confirmation of the hypothesis that is being tested or a new hypothesis being formulated and the cycle would repeat itself (Klahr & Dunbar, 1988). This model of science learning could be used to structure KS3 Science lessons to improve attainment. Furthermore, memory was stated to play a significant role in SDDS as there is a need for retrieval of prior knowledge and the need to process quickly observations made from experiments. In the literature there are cognitive ideas that could be construe as representing LTM and WM however these memory structures are not mentioned by the authors (Klahr & Dunbar, 1988). The SDDS model is about scientific thinking and reasoning skills to improve learning without the mention of WM.

This method of teaching science could easily be attributed to the schemes of learning in KS3 science. It is important to consider that aspects of this models could be impacting on the attainment of the participants in the study. Hence, I included lesson observation, student interviews and student, teacher and teaching assistant questionnaires to be able to give me an insight into the any teaching models (or aspects thereof) that the active and control group could have been exposed to and what impact that may have on their attainment that could not explicitly be attributed to WM development. This helped to shape the approach I had to my study.

2.3.5 Education Programmes, Strategies, and Initiatives; the evidence for the efficacy of these is considered including a discussion on strongly held beliefs about strategies used by teachers that have little or no evidence base

In recent years the need for evidence-based research in Education has replaced educational fads and phases that had no real basis in fact and no supporting evidence. Ideas and initiatives such as putting interactive whiteboards in all schools in UK has not improved teaching significantly (Willingham, 2012) . In addition to which, project learning and group learning need pedagogical expertise as with the interactive whiteboard doing those activities on their own does not mean teaching will improve (Willingham, 2012). Some researchers think that teachers should be taught the consistent information from child cognitive psychology motivation, cognition, and emotion for example the idea that students can only process one thing at a time – so get easily overloaded with information, instead of using non-evidence-based strategies to improve learning in the classroom (Willingham, 2018).

Furthermore, people including “teachers, politicians and educational policy makers” (Kirschner & De Bruyckere, 2017, p. 135) have been stating that the digital natives are able to multitask. However, although these students were born in an age where they have always had the internet and high-tech devices to interface with, there is little supporting evidence that digital natives are able to multitask. So contrary to the people that digital natives ought to be taught differently because they would be able to get information and multitask easily. There is in fact little if any evidence to support this argument (Kirschner & De Bruyckere, 2017). In fact, students still need to be taught information and how to search, sort through and identify important information, wherever and whatever they are researching.

The term digital native was coined based on observations of children and young people being surrounded and constantly using technology. However, this observation led to an assumption based in fiction that young people are using this technology in an in-depth way to find out and evaluated information. There is a wealth of evidence to contradict this assumption (Kirschner & De Bruyckere, 2017)

There have been claims that digital natives are able to multitask. There is no evidence to support these claims. There is however evidence that supports the idea that digital natives are adept at task switching (due to the number of devices that they are exposed to) this means that they are less able to inhibit irrelevant information and more likely to not be able to focus on the task in hand for long periods of time. This tends towards digital natives' task switching being detrimental for their learning (Hassed & Chambers, 2014; Kirschner & De Bruyckere, 2017). There is evidence to suggest that any tasks that require thinking can only be done one at a time. The best humans can do is switch between one cognitiviely demanding task and another. This seems to be less efficient then doing one task at a time. There is evidence to support this on a cognitive psychology level and on a the level of how neurones carry information in the brain (Kirschner & De Bruyckere, 2017). There is some evidence that students who spend a lot on social media platforms, gaming and watching television have a smaller WM (Kirschner & De Bruyckere, 2017)

There has been historically, a huge investment in the learning styles initiative in schools both nationally and internationally. As a result, there has been huge teacher and student excitement and engagement with individual learning styles for nearly two decades. The evidence this type of pedagogy is based on is flawed and there is no objective evidence that being taught in a preferred learning style positively impacts on the learning of the student (Kirschner, 2017). Students might have a preferred learning style but this might not help them learn, furthermore the learning styles tests are not reliable – people do not get the same learning style preference if they take the test more than once (Kirschner, 2017).

> *"1. The premise that there are learners with different learning styles and that they should receive instruction using different instructional methods that match those styles is not a 'proven' fact, but rather a belief which is backed up by precious little, if any, scientific evidence.*
>
> *2. There are a lot of very fundamental problems regarding measuring learning styles.*
>
> *3. The theoretical basis for the assumed interactions between learning styles and instructional methods is very thin.*
>
> *4. Significant empirical evidence for the learning-styles hypothesis is almost non-existent."*
>
> (Kirschner, 2017, p. 170)

There is a risk with initiatives that are launched with a lot of CPD investment (in both time and money) that teachers enthusiastically introduce the initiative into the classroom. Then the Pygmalion or Rosenthal effect occurs. This is when teachers expect increased attainment or learning from students then teachers will get increased attainment from those students (Kirschner, 2017). The increase attainment occurs due to the expectation of the teacher not the initiative itself.

Furthermore, there is a belief that people born after 1984 have developed metacognition skills due to their immersion in technology. However, there is little evidence to support this idea that Digital Natives have metacognition skills that enable them to do progressive types of learning such as active learning, enquiry based learning and experiential learning. (Kirschner & Karpinski, 2010, p. 1238) Although digital natives are able to "Google®" information the evidence demonstrates that they have not developed the necessary skills to discern if the information they are reading is correct or to evaluate the information's authenticity or bias or to be able to identify from large swathes of information the relevant parts of the text (Kirschner & Karpinski, 2010). In addition to which, when students are regularly using Facebook® whilst studying the task switching appears to have a negative impact on their academic performance (Kirschner & Karpinski, 2010)

There were 7 teachers in total delivering Science lessons over the two-year period to six classes. These teachers varied in experience, and teaching strategies and beliefs. So, their choice of strategies that they used to deliver lessons may have been influenced by many of the educational strategies that have not been founded on evidence-based research. This literature informed the study by ensuring that I included lesson observations, student interviews and student, teacher and teaching assistant questionnaires to be able to give me an insight into the teaching strategies employed with the active and control group and what impact that may have on their metacognition, perception of memory and learning and the impact on attainment that may not be attributed to the WM activities. This both shaped my approach to the study of a mixed-methods quantitative and qualitative data gathering and also started to shape the two research questions:

What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, Science and learning in Science compared to the control conditions?

What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

2.3.6 Evidence based programmes, strategies and initiatives are discussed and their possible contribution to KS3 Science attainment (including discussion on the impact on the results of the thesis research)

The Self-Regulation of Learners (SRL) and hence metacognition is implicitly within the lesson plans in the SOL lesson plans that have as an integral part of each lesson the activities to develop WM. The SRL and metacognition have undoubtedly been made explicit by some of (if not all) the teachers who delivered the activities to develop WM (as an integral part of the lesson plan) this thesis research is based. Is the self-regulation of learners and metacognition that the students undertake as part of the activities to develop WM (as an integral part of the lesson plan) able to make them better learners?

The increase in attainment seen during the preliminary study could be attributed to the self-regulation and metacognition of learners and not an increase in WM. It has been demonstrated that students who have to write and share summaries of what they have learned with peers become better problem solvers (Pilegard & Fiorella, 2016). Self-Regulated Learning (and Metacognition) is an umbrella term for a range of teaching strategies (classroom activities) including rehearsal, summarising what has been learned, problem solving, planning work, students checking their understanding and evaluating their work and approaches to their work (Dignath & Gerhard, 2008). It also includes training of strategies for metacognition and self-regulation of learning (Dignath & Gerhard, 2008) . These strategies have been demonstrated to increase student's learning in the lower years of Secondary school (Dignath & Gerhard, 2008). However, with six fairly wide-ranging Self-Regulation of Learning Models and differential results within the same age groups and between age groups of students; this is not conclusive (Panadero, 2017). Also, it is important that alongside self-regulation of learning and metacognition, that teachers develop a safe learning environment where students feel safe to strive for aspirational targets (Panadero, 2017). Any increase in attainment in students cannot for certain be attributed to the Self-Regulation of Learners and hence Metacognition but may well be a contributory factor.

Distributed practice is the revisiting of materials periodically throughout the delivery of a particular curriculum; building a little more on the student's knowledge each time the topic is revisited. The research has provided strong evidence that it is effective way to support student learning within the context of memory research. Contextual and Coding Variability Research has presumed that this is causing the positive effects recorded in the research however this is being challenged by the newly observed and published findings called superadditivity and nonmonotonicity (Benjamin & Tullis, 2010) . Previous interventions have demonstrated positive results not just in laboratory testing but also when research takes place in classrooms. It is clear that distributed practice is not a new concept or idea and has been supported by many major pedagogical text books however this practice is not something that happens in all schools. However, the attainment in the first two years of Science in the research school is tested cumulatively in tests and information revisited in revision lessons and as part of a spiral curriculum.

If the aim is for students to learn new information which may require the addition of information into an already existing schema, or to build a new schema within the memory then the use of problem-solving techniques to support this learning is not effective. There is evidence to support the idea that problem solving activities take up too much cognitive processing capacity leaving very little to lay down new information in schemas. However, there is evidence to suggest that the teaching strategy for problem solving called elaborative interrogation is an effective approach that elicits learning in students. Elaborative interrogation involves students asking questions about a problem in order to help them solve the problem. On the other hand, elaborative interrogation was found to be most effective when students had already received lessons on the topic the problem was based on (Sumeraki, et al., 2021). Using elaborative interrogation with a problem on a new or relatively new topic evidence suggests may cause students to develop misconceptions, or consolidate already held misconceptions (Sumeraki, et al., 2021).

Teachers have in recent years had easier access to evidence-based teaching strategies, programmes, and initiatives for example; nationally with the Education Endowment Foundation and internationally with The Learning Scientists podcasts and supporting materials on their website.

The Education Endowment Foundation in 2014 published a “*A Review of Educational Interventions and Approaches Informed by Neuroscience*”. This review covered 18 initiatives including embodied cognition, interleaving and neurofeedback. Amongst the initiatives that were most effective were spaced learning and testing on previously learned material (retrieval practice). On the other hand, creativity and personalisation were shown to be least effective (Howard-Jones, 2014).

The Learning Scientists website and podcasts advocates six teaching strategies that have evidence within the literature that supports their efficacy. These are interleaving, dual coding, concrete examples, elaborative interrogation, spaced retrieval, retrieval practice and interleaving

(Sumeraki, et al., 2021). The podcasts are well balanced and clear to point out where evidence is weaker for a specific strategy or in a specific context. Teachers within the research school and other schools in the local area have been using the strategies advocated by The Learning Scientists. However, the impact of this in the research school has not been assessed.

Assessment for learning became a big pedagogical talking point just before the turn of this century. The publication of Black and Wiliam's *Inside the Black Box* lauded the advantages of assessment for learning. Including effective marking policies that meant that students were given clear feedback on how to improve (Black & Wiliam, 1998). The evidence strongly suggested this to have the biggest impact on the least able (Black & Wiliam, 1998). The changes (and possible increases) in attainment that may be seen within the lesson plans that have as an integral part the activities to develop WM could be down to the Science department marking policy. The students have marked regularly with *strengths and targets.* When the students act on the targets, this should enable students to make progress with the aspect of science that they are studying. This policy was being used by the researcher during the preliminary action research study that demonstrated the science specific activities to develop working memory having a significant impact on the Science attainment of the students. The formative assessment that the students were exposed to including effective marking and feedback, peer marking, reading, and improving their own writing could have enabled students to become better learners; this and not the development of WM could explain the increase in attainment observed during the action research study.

The teachers that delivered the Science lessons to the participants will have deployed a range of strategies to teach Science to their classes. Some of those strategies may have been evidence-based teaching. This coupled with the formative assessment that was the marking policy of the school may well have had an impact on both the attainment of the students, their metacognition and their perceptions of learning, memory, and Science. This knowledge from the literature has informed the approach to my study. Hence, I included lesson observations, student interviews and student, teacher and teaching assistant questionnaires to be able to give me an insight into the teaching strategies and the impact that may have on the participants attainment that could not be attributed to and what impact that may have on their attainment that could not explicitly be attributed to WM development. This helped to shape the approach I had to my study and also the development of two of the research questions. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, and learning in Science compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

2.3.7 Science specific interventions that may improve KS3 Science attainment; and a discussion on their efficacy compared to using activities to develop WM (and hence KS3 Science attainment)

There are only a small number of domain specific interventions or programmes which claim to increase Science attainment. However, after Adey and Shayer's work was published in 1993 and 1994; Cognitive Acceleration in Science Education (CASE) became a popular initiative within English Schools (as well as other countries around the world) (Adey & Shayer, 1993; Adey & Shayer, 1994; McLellan, 2006). CASE was intended for use with Year Seven and Year Eight students. There have been widely held beliefs that CASE had a significant impact on the Science attainment and that there were also far transfer results to other curriculum areas (Oliver, 2016). There was evidence to support the CASE intervention having a positive impact on the science attainment of students in schools in low socio-economic areas compared to similar schools that did not have the CASE intervention (Venville, et al., 2012). The intervention also seems to have had a positive impact on the numeracy and literacy skills of the participating students who did better on national tests than those students in similar schools who did not have CASE intervention (Venville, et al., 2012). A further study by Venville and Oliver focused on the students of an academically selective high school in Australia. The evidence suggests that the selective high school had the greatest gain in academic attainment in

Science compared to a non-selective high school using the CASE intervention. Both groups using the CASE intervention appeared to show better attainment then students in a control group who did not have the CASE intervention (Venville & Oliver, 2015).

However, CASE was not completely embedded in the Year Seven and Eight curriculum; within the CASE initiative there are 30 lessons. Each class in Year Seven and Eight should have a CASE lesson delivered once a fortnight. There was a full CPD training program available to teacher which included training away from and within the classroom (Adey & Shayer, 1993; McLellan, 2006). This obviously incurs a cost that in these current times of national education funding austerity is CPD that schools would be hard pushed to fund.

CASE has been used as a lesson approach and intervention to increase attainment in Science (CASE). CASE was widely acclaimed in 1990s as a pedogogical approach to lessons that appeared to result in an increase in Science attainment (Adey & Shayer, 1993; Adey & Shayer, 1994; McLellan, 2006; Oliver, 2016; Venville, et al., 2012; Venville & Oliver, 2015) . However, there is evidence to suggest that students within the CASE lessons can develop learned helplessness and self worth motivation difficulties this may lead to the intervention not having a positive impact on their science attainment (Leo & Galloway, 1996).

On the other hand, another classroom strategy is emphasis on literacy in a lesson plan has been hailed as an initiative that may increase in attainment. Research appears to demonstrate that an intervention involving reading domain specific literature can have a positive impact on attainment when secondary students read both general and subject specific text within lessons. Both reading achievement and school attainment were significantly higher after the intervention. (Kuin Lai, et al., 2014).

The individualised student instruction is another strategy that is being used to improve Science attainment in second grade age students. Individualised or differentiated reading materials were presented to groups of students who had been grouped according to their reading ability. Students accessed this reading material within their Science lessons. The evidence suggests that

Students' literacy and science attainment both increased. This strategy of delivering science may have an impact on science attainment and literacy (McDonald, et al., 2010). However, this study just looked at the impact of this one strategy and was not comparing the efficacy of one strategy to another hence there was no active control. The intervention of using differentiated reading resources also demonstrated a possible positive impact on the reading comprehension in students from poorer backgrounds (McDonald, et al., 2011). On the other hand, the study does not look at attainment in other subjects linked to that increase in reading comprehension. Hence the effect science specific differentiated reading materials being used in lessons would have on student attainment in science is equivocal.

CASE is a well-documented intervention that had an impact on student science attainment and in some studies more widely in other subjects. The fact there were other interventions that were not WM training related that had far transfer effects helped to shape RQ c. Far transfer effects are not usually reported in WM training research. The impact of a non-WM related intervention demonstrating far transfer made me realise that a WM training intervention may possibly have near transfer and also far transfer effects. This helped to shape the RQ c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions? Furthermore, the domain specific literacy focused Science interventions made it clear that there were reading and literacy-based activities that had an impact on attainment without attributing it to WM. A major aspect of the WM activities is the reading sheets and writing activity. There needed to be some consideration to collating data from lesson observations, student interviews and student, teacher and teaching assistant questionnaires to be able to give me an insight into the perception of the impact of the activities on the students of all those who took part in the study. This help to shape my approach to the study and also shaped the metacognition and perception research questions: What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory and learning in Science compared to the control conditions?

What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

2.3.8 Conclusion

There is a wide range of published literature into cognitive models, cognition and learning and other teaching strategies, initiatives and programmes that claim to increase academic attainment generally and specifically in Science. The outcomes of the data analysis will be considered within the context of other factors (which have been discussed here in this Section) alongside the WM research. The literature identified in these areas has helped to both shape my study and inform my research questions.

2.4 Working Memory is Important for Learning

2.4.1 Introduction

The literature for this Section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 29 (Appendix A) Shows the literature, how it was selected and a summary of how it was useful to inform the literature review of Working Memory being important for learning.

2.4.2 Defining Working Memory as a key construct and justifying the importance of comparing and contrasting WM models

WM is the part of our memory that allows us to take in new information from our surroundings by hearing, seeing, reading, and understanding where we are in relation to our environment. The WM takes this new information processes it (using executive function) and links it to information in the long-term memory. This makes new memories. Extensive reading about WM had led me to have the perception that this is how learning happens in a classroom.

Hence, it was imperative that this study had a model of WM that reflected how I thought learning was occurring in the classroom; which was also supported in the literature. Section 2.4.3 takes the findings and theory of the various models of WM and compares and contrasts them with the WM model chosen to use in this study. This illustrates and justifies that the many of the models are not useful in studies that are researching the link between WM and learning.

When I first did the action research into WM (as outlined in Chapter 3 Method and Methodology) I used attainment to measure the impact of the WM activities used in lessons. However, in order to answer the overarching research question (What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?) and research question a (What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?). I needed to be able to measure WM.

Section 2.4.3 explores the theories of the differing WM models and compares and contrasts the different parts of the memory that they include. The difficulties in measuring some of the parts of the memory in many of the WM models is discussed. An argument is also presented as to why I chose the Baddeley and Hitch model of WM with its measurable parts of the model. The WM being measurable and hence quantifiable informed my overarching research question and research question a (as stated above).

Section 2.4.4 discusses the findings and theories from the literature about the Baddeley and Hitch model of WM. This is used to justify the reason for using this model in this research study. How the Baddeley and Hitch model of WM is was pivotal in constructing the theoretical framework of the study is discussed later on in the literature review.

2.4.3 The Differing Working Memory Models and how they convey that Working Memory is Important for Learning

This Section will review the literature that covers the various models of WM. A range of different models of WM have been considered and discussed below; these all can be linked to learning in a secondary school setting. This section also includes a justification for the use of the Baddeley and Hitch model of working memory for this research and how this specific model links to the activities to develop working memory that I have developed for KS3 Science lessons.

There are a number of challenges to face when researching WM. Notwithstanding, that there is not just one model of WM but various models (Cowan, 2022)(see Figures 5 – 11). It is broadly agreed that WM is linked to learning, and the various models of WM all link to learning. Cowan (2022) would argue that attention focus is the key to learning, as this activates the WM in his activated LTM model of WM. This links to having the appropriate amount of cognitive load for learning to take place; too little cognitive load and the WM would not be activated within the LTM, too much cognitive load (overload) then learning is unable to take place (Cowan, 2022).

To summarise other WM models, WM has been stated as being linked to executive functions (EF) and fluid intelligence (Gf) and that there is an overlap or that WM CE is EFs (Figure 5) and there is a large overlap with Gf (Figure 7) others have WM as a smaller construct (Dehn, 2008). WM theories that have links to STM do not have explanations of how WM relates to LTM (Figure 8). WM theories that state it is a subsection of LTM do not explain how it is related to STM or has limited and separate capacities (Figures 9 & 10). As well as those models who have attentional control as an activator of memory (Figures 11a & 11b).

The Baddeley and Hitch Model of WM (Figure 4) will be discussed in this Section of the literature review. This will include a justification of its' use in the research framework design compared to other WM models.

The challenge as a researcher is to how to measure WM (Chapter Three and Appendix B) and to make a discerned and well-informed choice as to which model of WM to work with. This is particularly challenging given that the WM models are so diverse and have evidence that supports such a range (Cowan, 2022). It is important to take into consideration that the big areas of future memory research are those that will demonstrate how different areas of the brain that contain different parts of the memory physically interact with one another (Kandel, 2005). This includes how WM physically interacts with LTM; it has simply not been discovered yet (Kandel, 2005). More recent research has incorporated WM training and neuroimaging into the same study. Demonstrating that WM increases with WM training and demonstrating physically in the brain where changes have occurred (Jones, Adlam, Benattayallah, & Milton, 2022). However, this sort of research is in its' infancy. In short, all the models of WM are just that models and at this time it is not known how all the physically different parts of the brain that are linked to memory and learning interact. But despite this as a researcher it is vital to consider all the models and what impact they may have on the methodology, method, and analysis of the results for this thesis.

The widely accepted Baddeley and Hitch Model of WM (Figure 4) gives an excellent framework of WM to test in a classroom setting (Alloway & Gathercole, 2009; Fenesi, Sana, et al., 2015; Holmes & Gathercole, 2014). However, the attention focus of students, information students already have stored in their LTM, the students' ability to apply their fluid intelligence (Gf) and executive functioning skills all contribute to learning new information. The other models of WM were considered in both shaping the research and in particular how the results are analysed. This will ensure any findings from the research have more validity and withstand in-depth critique of any conclusions drawn.

Figure 4 The Baddeley and Hitch Model of Working Memory

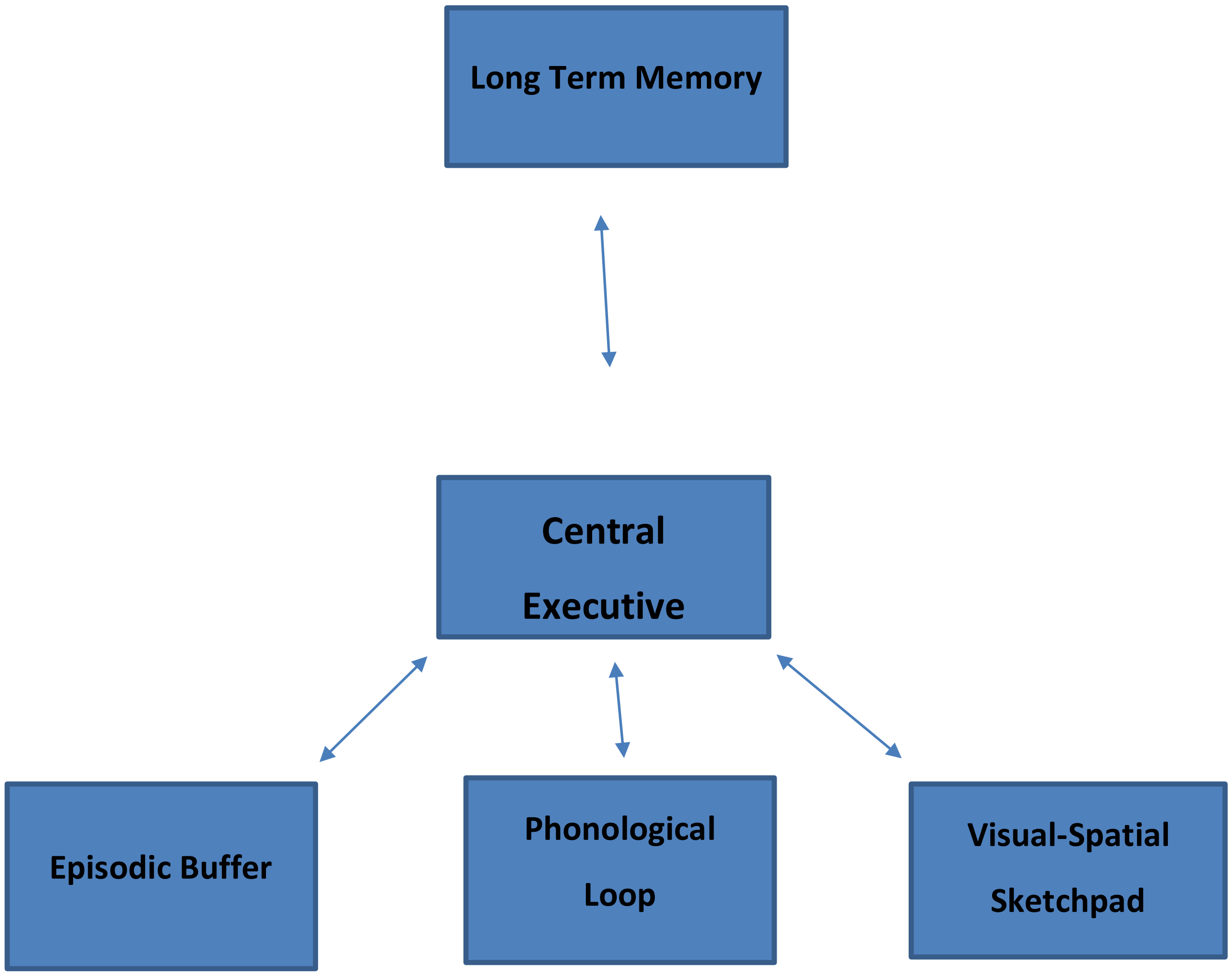
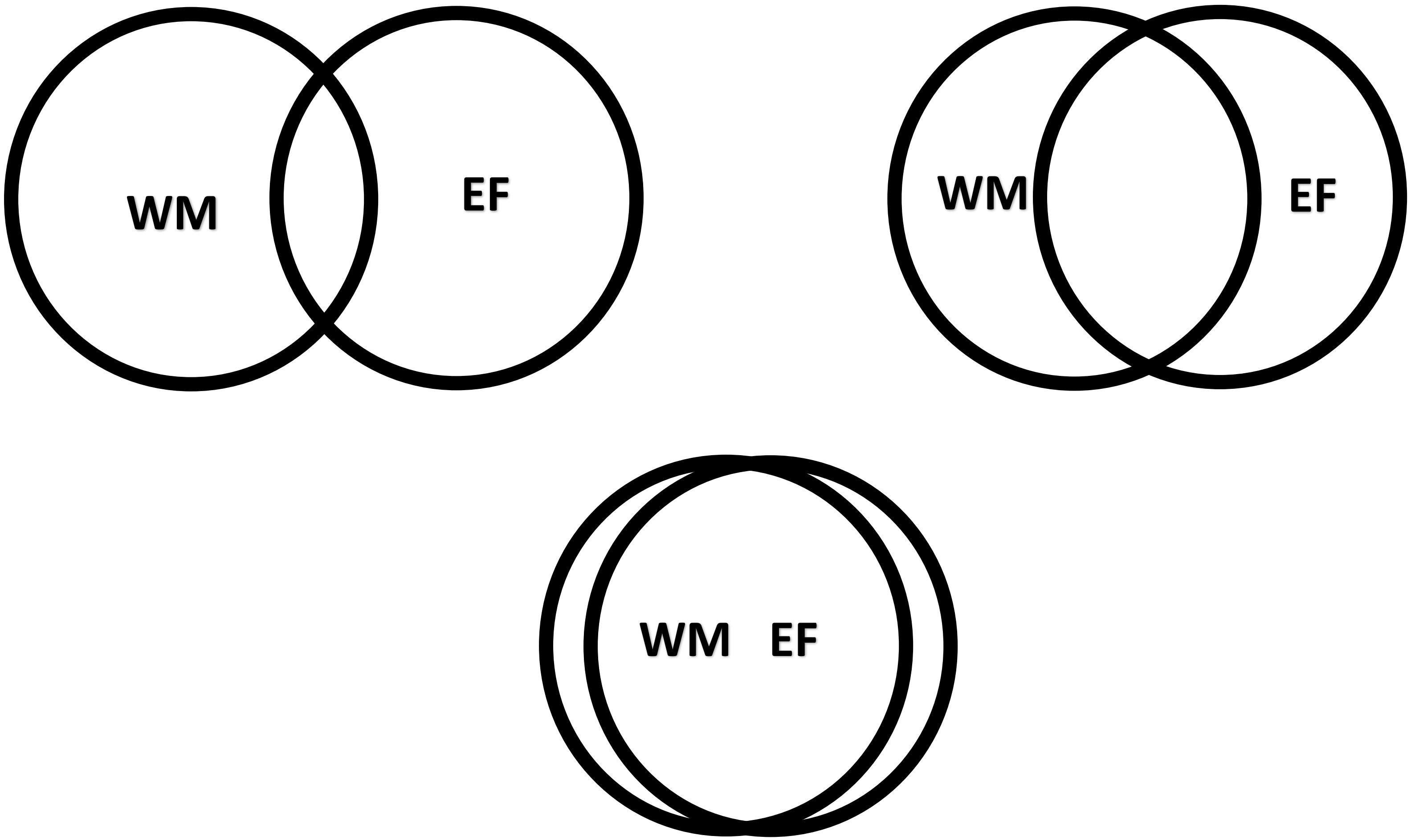


Figure 5 A diagram to show different perception of researchers (e.g Smith, Jonides, & Koeppe, 1996; Engle R. W., Tuholski, Laughlin of the relationship between Working Memory and Executive Function



There has in recent years been some focus into WM and EF. This research has included investigating what parts of the brain are used for EF and if the central executive (or WM as a whole) has some EFs within its’ construct(s) (Figure 6) (Baddeley, 2001; Dehn, 2008; Engle, et al., 1999; Smith, et al., 1996). This has gone alongside and sometimes included (as previously mentioned) for a good many research teams adopting different models of WM such as the embedded- processes model (Figure 7) or the attentional control model (Figures 11a &11b) (Fenesi, et al., 2015). Researchers have been investigating if WM is linked to the EF of intelligence and specifically Gf. Furthermore, other researchers are investigating how LTM links to WM (overlaps with EF) and intelligence (Figure 7). During the rest of the literature review where EF is mentioned this is because either the paper identified an overlap with WM or because EF has been used in a research paper as a synonym of WM (Figure 6).

The Baddeley and Hitch model of WM includes the CE that is the EF of the WM. The research that looks for links between WM and EFs is important to include within the literature review. The literature indicates that the EF of students is part of the WM (Baddeley & Hitch, 1974; Engle, et al., 1999; Ericsson & Kinsch, 1995). Furthermore, the evidence indicates a link between the speed of executive functioning and childhood development of intelligence (Demetriou, et al., 2014). Hence, it is important to consider the different aspects of executive function (EF) and how they can contribute to learning and henceforth the Science attainment of KS3 students. Because these EFs (including Gf) enable students to be able to complete cognitively demanding tasks in the classroom and hence these students will have higher attainment due to better learning. If students have weaknesses in these areas, they will not be able to complete cognitively complex tasks and they will not attain highly in the classroom possibly underachieving at school. This thesis is about a science subject specific activities that potentially develop student’s WM and hence improves their attainment in Science; counteracting that effect.

In order for students to learn at school they must pay attention to the information that the teacher is communicating to them. In contrast to the Baddeley and Hitch Model other researchers think that attention focus and the central executive and memory are closely related (Figures 9, 11a & 11b)(Anderson, 1990; Cowan, 2014; Fenesi, et al., 2015; Engle, et al., 1999; Oberauer, et al., 2000; Tehan, et al., 2001). The research undertaken in this thesis involves an outline lesson plan that has three different science specific activities (created by myself) which require students to focus on individual tasks of listening, reading, or writing that will tax the WM. Some researchers have concluded that WM is a subset of LTM (Dehn, 2008; Ericsson & Kinsch, 1995) whereupon WM is activated due to attention focused (Cowan, 1988) on a specific task within the WM activity (Figure 9). Hence, other models show that WM does not have a limited capacity that may be improved by using the activities to develop WM being researched in this PhD thesis. The WM processing and ability to hold onto information may only be limited by the level of attention focused on a point of learning within a lesson (Dehn, 2008). Hence, increasing the students' ability to focus will improve the efficiency of WM processing of the WM and this may or may not increase the ability of students to learn nor increase student attainment. This is in direct conflict with the neuroplasticity research that WM can be improved, hence improve learning, and therefore increase Science attainment. This may be critically considered when discussing the findings of students' WM function pre- and post-research.

Students who are listening, reading, or writing have their attention focus on the task during the lesson. This attention focus enables the WM executive processing to be maximised and allows students to inhibit irrelevant information (Engle, et al., 1999). This is in partial contrast to the model that WM is a subset of LTM but with some storage capacity (Cowan. 2014) other theories consider WM a subset of LTM but just with the executive functioning part and no storage capacity (Figure 10) (Engle, et al., 1999). Furthermore, this WM model links WM function and capacity to the general factor of fluid intelligence (Gf) (Engle, et al., 1999). The controlled attention that students exhibit during the Science specific activities to develop WM this PhD thesis is based on impacts on the relationship between WM and Gf (Engle, et al., 1999). The Engel, et al. model may be important to take into consideration within an Education Research context because if WM and Gf are closely related increasing WM may well increase Gf (Figure 7).

Figure 6 Different researchers' theories of the relationship between Working Memory, Executive Function and Fluid Intelligence

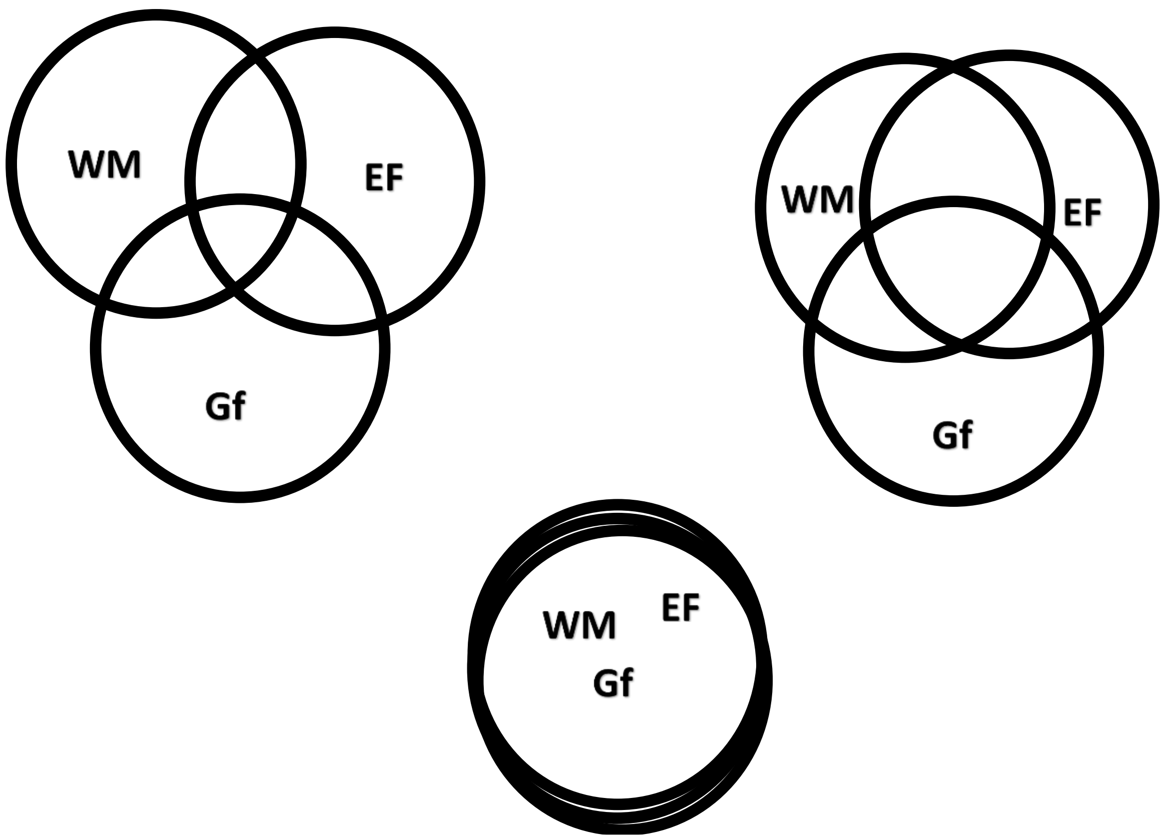
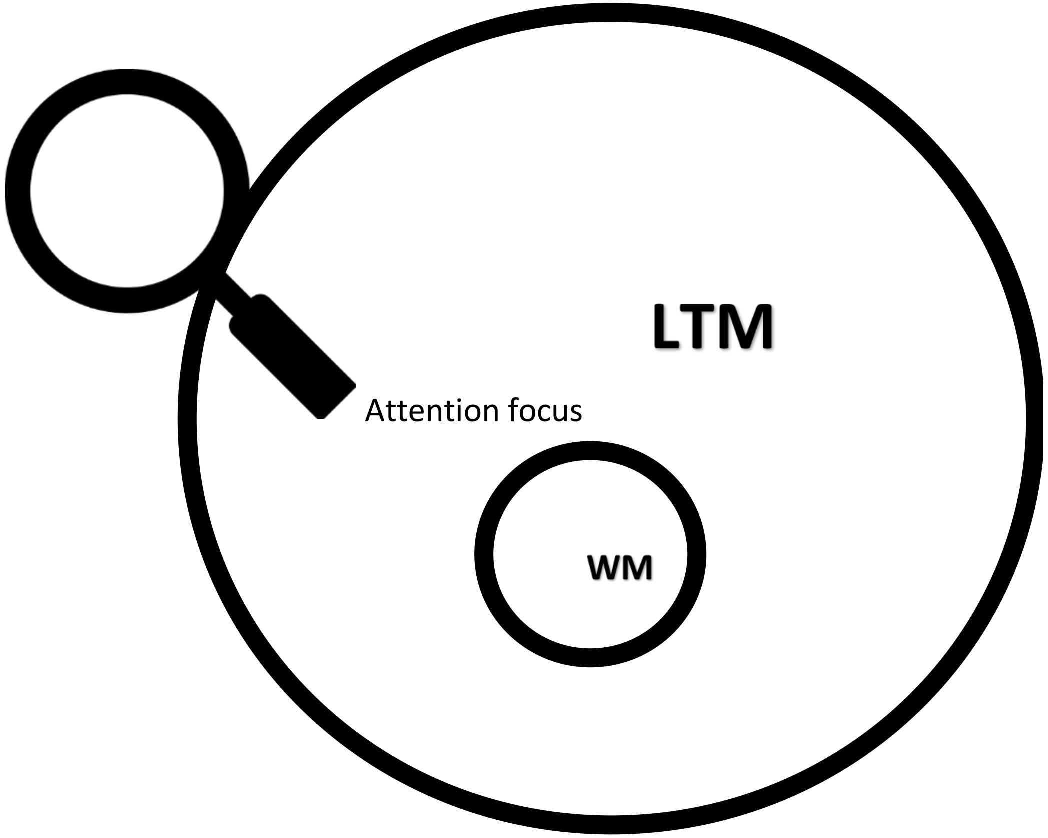


Figure 7 A diagram to show the model of Working Memory that has Working Memory Being Able to Share Information with the Short-Term Memory

Figure 8 A diagram to show the Long-Term Memory Model of Working Memory. Working Memory is a subset of Long-Term Memory. Attention must be focused on information in the WM to activate the WM links with the LTM



The alternative to this theory is that WM *is* a subset of LTM however that the WM has the same components as the Baddeley and Hitch Theory (Ericsson & Kinsch, 1995). The Long-Term Working Memory Model may have implications to the context and research content of this PhD thesis. This is because the way students initially commit information to their LTM alongside the enriching educational experience the Science specific activities (as an integral part of a lesson plan) being researched could deliver to students may have a positive impact on students LTM. This in turn means that any retrieval of information demonstrating science attainment would be coming straight from LTM and not STM storage (Ericsson & Kinsch, 1995). If this model is proven to be correct this will mean that pedagogically how students commit things to LTM will have an impact on how they learn new information in the future (Dehn, 2008). This specific model may also need to be considered when drawing conclusions and critically discussing findings.

The Long-Term Working Memory Model has similarities to the more conceptual Dual Component Model of WM. where new information is kept in the WM and attention is focused on it to ensure it is not lost. Whilst then allowing LTM information relating to new information to be activated and linked to the new information. The WM also ensures that irrelevant information is disregarded using the related information from LTM (Fenesi, et al., 2015). Both of these models are very difficult to apply to educational research because it is hard to find reliable tests that can individually identify the functions of those concepts. "As a result, research investigating optimal teaching and learning strategies must rely on theories of memory, such as multicomponent, embedded processes and attentional control models, which can be widely applied to educational research." (Fenesi, et al., 2015, p.347). This is best seen in the Baddeley and Hitch model of WM.

Hence, the widely accepted Baddeley and Hitch Model (Figure 4) of WM gives the research an excellent framework of WM to test in a classroom setting (this will be justified in the next part of this Section). However, the other models of WM may contribute important aspects to the way this research was shaped and how memory, learning and attainment results are analysed. The attention focus of the students, their initial information they already have stored in their LTM and the students' ability to apply their Gf and executive processing skills to learning new information. This may have a possible impact on some constructs of the differing WM models on the students' WM and their Science attainment measuring and or gathering qualitative data. The findings of the research may be discussed using a wider range of WM models this could lead to the conclusions to have more validity and withstand in depth critique of the conclusions drawn (Figures 6 – 11b).

However, due to the overlapping constructs and lack of tests to measure the constructs within the other models of WM; the Baddeley and Hitch WM model is used widely in education research and hence is embedded within the theoretical design frame work for this PhD thesis.

2.4.4 The Baddeley and Hitch Model of WM and how it conveys that Working Memory is Important for Learning

This research doctorate will be using the Baddeley and Hitch Model of WM (first developed in the 1970s) (Baddeley & Hitch, 1974) as it is able to offer an evidence-based model for how learning occurs in the classroom (Figure 4). However, where appropriate the other models will be used within the discussion of findings to critically reflect on any conclusions made. Baddeley and Hitch's widely accepted theory of WM was developed in the early 1970s (Baddeley & Hitch, 1974). This model includes the phonological loop and audio-visual sketchpad these parts bring information in from the environment via auditory and visual pathways. Also included is the episodic buffer; these three pass this information to the central executive that has the role of processing the information (Figure 4). This model states that WM is the mental note pad students have in their minds where they hold and manipulate information over a short period (Baddeley, 2014). Hence, WM is how students in a classroom take in and process new information; in order to learn that new information.

The original model of working WM had the phonological loop (auditory processing), the visuo-spatial working memory and the central executive (Baddeley & Hitch, 1974). The phonological loop and visuospatial working memory passed information to the central executive. The central executive would use information from the LTM to process this information and if necessary, allow the information to be committed to LTM. Support for the Phonological Loop of Baddeley's model has come from the recency effect and an experiment completed by Cowan. "…The fact that little or no rehearsal occurred is borne out by the finding that subsequent long-term retrieval of items at the end of the list is poorer than the items at the beginning or middle indicating that earlier items were rehearsed and encoded into long-term storage" (Cowan, et al., 2005, p.19). Hence, this model of WM demonstrates how in order to take on new information in a classroom; the size and or efficient of the different components of WM and how they store and process the new information is vital for storing information in LTM. This is learning (Figure 4).

The original model became problematic as a way to explain learning because the central executive had no storage capacity. However, some tasks that required LTM as well as EF were observed in individuals during research i.e., chunking (Miller, 1994 (1956)) of information that required input from LTM, the visuospatial sketchpad and the phonological loop (Baddeley, 2001). As a response to this research, the episodic buffer was added to the tripartite model (Figure 4). The episodic buffer holds onto information which, has been processed by the central executive or is a structure where information from LTM can be held. The episodic buffer can hold onto this information for only very short periods of time (Dehn, 2008). The episodic buffer is important for learning as it stores processed information that has new information from visuo-spatial sketchpad and the phonological loop or related information from LTM; which has been processed by CE. The episodic buffer then enables the new information to be stored in the LTM. This model of WM indicates that new information presented to students within a science lesson could not be learned without the episodic buffer. This means students would receive input of information from a lesson and be able to temporarily retain that information in the episodic buffer whilst retrieving linked information from a LTM schema. The CE would then process both the new and LTM information and place the new learning in the LTM. If these constructs increased in size and or efficiency then an increase in WM and an increase in attainment may be seen.

The central executive part of the model was developed, based on individuals who would struggle to process information when remembering a set of numbers. Those results demonstrate the idea that some of the WM function is delegated to the slave systems of the phonological loop and audio-visual sketchpad enabling information to be processed at the same time by the central executive (Baddeley, 2014). Examples of when people use WM could be hearing and trying to repeat an unfamiliar word in a foreign language, mental arithmetic and following aurally given instructions (Baddeley, 2014). These are all experiences that a KS3 student would have on at least a weekly if not daily basis. Hence this model provides the researcher with a clear idea of how information that is delivered to students in a classroom is temporarily stored, processed, and becomes part of the LTM. This clearly leads to students remembering straight forward facts this would lead to learning: in other classroom scenarios this remembering would need to be further processed and linked to ideas or learning already established in the LTM schemas. This processing is an EF. Hence WM and learning has an overlap with EF (Baddeley & Hitch, 1974; Engle, et al., 1999; Ericsson & Kinsch, 1995) thus supporting learning and hence increasing their academic attainment in Science; the chosen field of research for this PhD thesis.

Figure 9 A diagram to demonstrate the Embedded Processes Model (synonymous with the Dual Component Model) in this model the Central Executive is a Subset of LTM but there is no storage (as provided by the slave systems in other models*)*

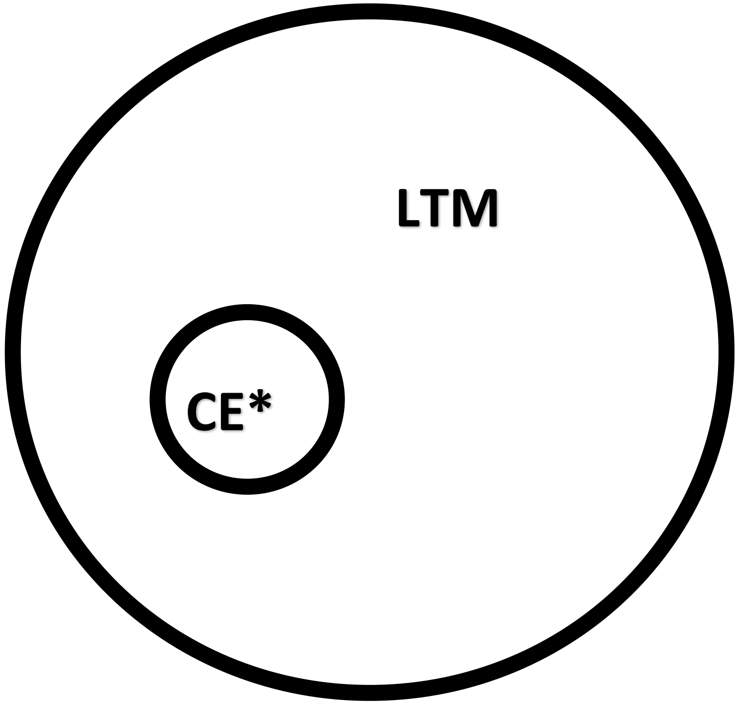


Figure 10 Attentional Control Models

Figure 10a: In this model attention must be focused on new information and also stored LTM information in order to make new memories.

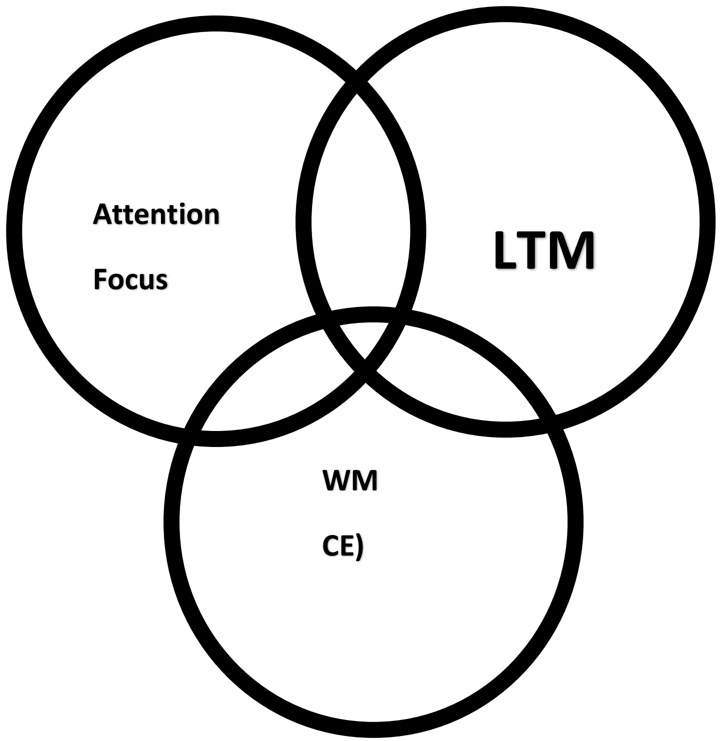
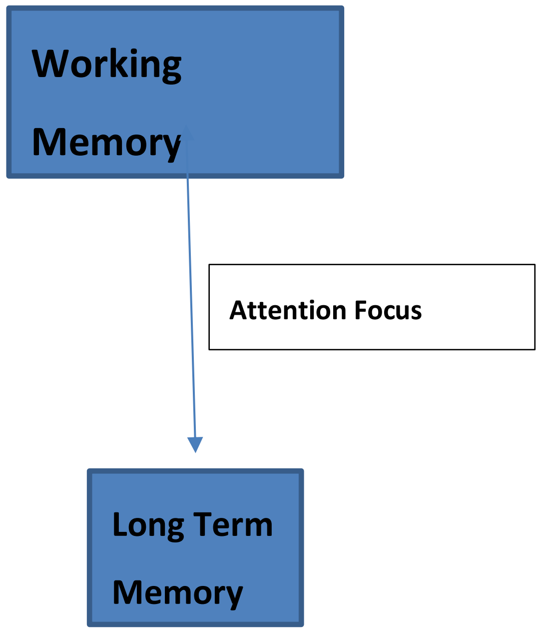


Figure 10b: In this model in order to store new memories attention must be focused on new information and this activates the relevant information (related to the new information) in the LTM.



2.5 Working Memory is important for learning in a school setting

2.5.1 Introduction

The literature for this Section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 31 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of how Working Memory is important for learning in a school setting.

2.5.2 Establishing why WM is important for learning in a school setting

One of the seven key constructs examined in this literature review is that WM is necessary for learning to take place. The Baddeley and Hitch model of WM discussed in section 2.4.4 is chosen as the most useful when researching the impact of WM on attainment. This is because it is made of several key components that interact to enable new information to be taken in, processed, and committed to long-term memory as a new memory. This is how I define learning.

Figure 4 shows how new information such as listening to information, following instructions, or reading information can be taken in by the visual-spatial notepad and phonological loop and held by the episodic buffer. Whilst information already learned is retrieved from the long-term memory and the new and old information are processed and linked together using the central executive and new memory is now formed in the long-term memory.

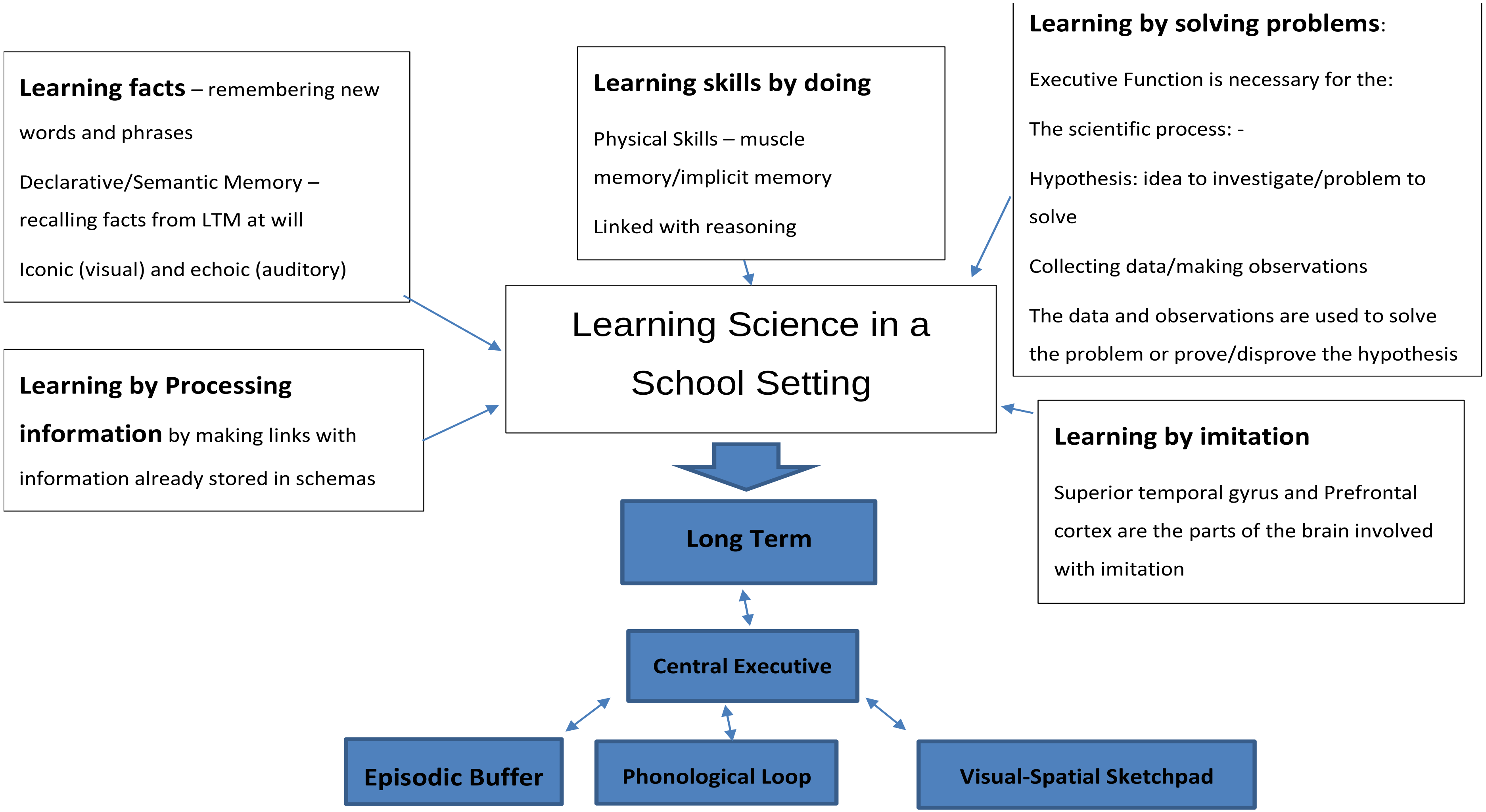
The Baddeley and Hitch model is seen in the context of how learning occurs in a secondary school setting in Figure 11.

The findings and theory from the literature about the key construct of WM being necessary for learning are discussed in this section in relation to learning in a school setting. These have helped to shape the overarching research question and three of the five research questions. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students? What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory and learning in Science compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

This Section discusses the literature on learning in a school setting that is attributed to WM function juxtaposed against literature that supports learning in a school setting without the explicit need of WM constructs within their findings or theory. The findings and theory from the literature were then used to formulate the research questions stated above. The contradictory findings and theory in the literature will be used in the discussion to critique the findings of the study.

There is some contention over learning and remembering. But learning in this context is about remembering facts and skills, and being able to process new information, make links and store this new information (and or the links made) in the LTM (Figure 11)

Figure 11 The researcher's perception of how learning Science occurs in a Secondary school setting



Students usually learn if they are able to process the new information and relate it to information they already know. If the student has no prior knowledge of this new information, then they will have to start building a new schema (McLeod, 2015). This part of the literature review looks at national and international research that has found links between WM and learning Science. There are a good many research teams undertaking research to link WM with both Gf and or executive functions; all of these are vital to attainment in Science.

A student with just a WM weakness is likely to underachieve at school (Alloway & Gathercole, 2009). Furthermore, students with a learning disability are likely to have a WM deficiency as part of their profile (Alloway, 2009). The SEND students are tested as part of general cognitive assessments e.g., TOMAL (Reynolds & Voress, 2007)). At the heart of this research is a drive to increase science attainment in secondary school students. Learning Science in a school setting requires a basic set of skills. Being able to focus attention and being able to read, write and do mathematics. The Baddeley and Hitch model of WM has learning occurring by new information being processed and committed to LTM (Figure 11). There is also research that implies that WM (& EF) are linked too; or could possibly have an overlap with Gf. This evidence also points towards WM having an overlap with crystallised intelligence (Gc). The need for attention focus, a possible link to Gf and the research pointing towards WM being important for students to read, write and do mathematics; tends towards the conclusion that WM is vital for learning in a school setting. However, there is evidence that a two-year long intervention using diagrammatic reasoning is able to increase Science attainment without a focus on WM and its' impact on reading, writing and mathematics skills (Cromley, et al., 2016).

The Baddeley and Hitch WM model, says new facts have to go through WM to be committed to LTM so students can use these facts in cognitive tasks in school or at work (Figure 11) (Baddeley, 2014). Internationally there have been calls for there to be a paradigm shift in education. The classroom and delivery of content is not producing citizens with the correct skills to enable governments to build strong economies. However, the people calling for a radical change in how and what we teach our children have not considered WM (Abadzi, 2016).

The idea that students are multitasking digital natives and any fact can now be "Googled" so students do not need to be taught facts or how to learn facts is absurd. There is in fact little if any evidence to support this argument (Kirschner & De Bruyckere, 2017). More research needs to be conducted into WMs' impact on academic attainment and hence cognitive processing. If the people advising governments on educational policy do not have the information about how vital WM is to learning and attainment then the education of many students in many countries could be at risk. This in turn will have a negative impact on the economy of those countries (Abadzi, 2016). In contrast however other researchers have been focusing on student motivation (Bryan, et al., 2011) (Wang & Liou, 2017)being the key to learning and that making the Science curriculum personal to the student's lives (Prain, et al., 2017) both these have been shown to have an impact on Science attainment and Science learning without their being a link to WM.

Over the last 20 – 30 years there has been an increase in research using the Baddeley and Hitch WM model; into the link between WM and learning. It is evident from the research already commented on within this review that WM seems to be able to take information from the LTM (Long Term Memory). Furthermore, it is there is strong evidence that the CE processing abilities enables new information to connect to this information in LTM. This connection then enables the person to store new information in LTM. At the very least this research means that WM (and hence Executive Function (EF)) should play an integral part in the day-to-day planning of lessons. This would ensure that all students are able to process new information and commit this new information to their LTM. WM is the key to learning. There is a conflicting view that other factors may have just as an important (or greater) role in learning as WM especially in Science education including motivation (Bryan, Glynn, & Kittleson, 2011; Wang & Liou, 2017), diagrammatical reasoning (Cromley, et al., 2016) and making Science learning personal to students' life experiences (Prain, et al., 2017).

An increase in science attainment cannot occur according to the Baddeley and Hitch model of WM, without students committing new information to their LTM (Baddeley A. , 2014); and linking this information with existing information stored in the LTM. The link between WM, LTM and executive functions such as attentional control and learning has been the focus of authors and researchers for example (Hassed & Chambers, 2014; Miyake, et al., 2000). If students are unable to keep their attention focus on what they are learning then the new information cannot be committed to the long-term memory and hence be learned. In a busy learning environment such as a classroom, students may have visual information from a slideshow alongside the teacher who may also giving verbal input; this may cause students' WM capacity will be overloaded. This means that new information is not processed and hence not stored in LTM (e.g., Dehn, 2008; Fenesi, et al., 2015; Petty, 2009). In contrast there is evidence that suggests that when LTM is viewed with a Biologically motivated approach that students focus is effective at storing information in the LTM without WM models being used in the rationale (Kirstein, et al., 2008).

Links between WM, LTM, attentional control and learning have been the focus of some aspects of learning. It is the opinion of some researchers that learning cannot take place unless the WM function or capacity is sufficient (Hassed & Chambers, 2014). In addition, WM has been linked with executive functions such as attention control (Miyake, et al., 2000). Furthermore, in the book "Learning with the Brain in Mind" the link between paying attention and learning was made in particular there was a subsection entitled "Attention is key to plasticity of the brain" McNeil refers to research of Michael Merzenich and his brain plasticity training to support this claim (McNeil, 2009, p.156). Self-regulated learning (SRL) is important in academic attainment; also, SRL and EF are closely linked (EF is part of WM) (Duan, et al., 2010). The idea that training EFs (WM) will have a positive impact on intelligence and hence SRL and hence academic attainment (Duan, et al., 2010) (Figures 5, 7a and 7b). On the other hand, there is evidence that suggests that SRL has a positive relationship with writing strategies and writing ability in Secondary School students where researchers made no link between SRL and EF or WM (Teng & Huang, 2019).

There are researchers who have established links between WM and Gf (Demetriou, et al., 2014; Engle, et al., 1999; Honrnung, et al., 2011; Wang, Ren, Altmeyer, & Schweizer, 2013; Yeniad, et al., 2013). A strong link has been suggested that the ability of students to learn is linked to their intelligence. There have been some links found between WM and crystallised intelligence (Cowan, 2014; Wonguparraj, et al., 2015). However, a meta-analysis conducted in 2005 has evidence that points towards the WM not being the same as general intelligence; there is critique of the use of tests for IQ and WM being difficult to discern reliable results. There is also a suggestion that to get a clearer picture more evidence needs to be done in the area of WM and intelligence (Ackerman, Beier, & O'Boyle, 2005).

Furthermore, there is some evidence that indicates that WM, updating (EF) and Gf are closely linked (Lechuga, et al., 2014). On the other hand, there is conflicting evidence that tends towards updating and shifting (EF) not being closely linked to Gf. But this has to be viewed as a tentative conclusion as the research method did not include tests that explicitly measure updating and shifting (Friedman, et al., 2006)

The research indicates that EF is part of the WM (e.g., Baddeley & Hitch, 1974; Engle, et al., 1999; Ericsson & Kinsch, 1995). Furthermore, the evidence suggests that the speed of executive functioning and childhood development of intelligence are linked (Demetriou, et al., 2014) . Researchers do not always research EF in its' entirety but research a specific aspect of EF. In order to ensure all evidence is considered when building an argument to support WM being important to learning. It is important to consider the research that has focused on different aspects of EF and how they can contribute to learning and henceforth the Science attainment of KS3 students.

In the Baddeley and Hitch model of WM the EF aspect is the CE (Figure 4). There are three aspects to EF: updating, shifting and inhibition (e.g., Miyake, et al., 2000; Wonguparraj, et al., 2015). Updating is a key classroom skill as students have to constantly monitor their actions or written work to ensure they are still fulfilling the success criteria of the task. Shifting is also a vital skill to develop so that students can move from one piece of information to another. However, although the brain can improve the ability to shift seems to do so at the cost of being able to maintain focus on one task (Hassed & Chambers, 2014). This has led to concerns being expressed that inadvertently training or developing shifting (EF) in an unregulated manner could lead to students being unable to maintain focus on a task (Hassed & Chambers, 2014). This is likely to lead to those students finding learning more difficult or lead to student underachievement. Lastly, inhibition is imperative to learning; a student should be able to be selective with what information is important to complete the task and which information is distracting them from being successful at a task. Students undertaking the science subject specific activities to develop WM will be utilising all three of the aspects of EF (which overlaps with WM). In contradiction to this point is evidence that points towards conscientiousness of students and hence their attainment is only linked to the EF shifting. This research does not support WM and EF being the same constructs but with WM being just one part of EF. The evidence suggested WM was not linked to conscientiousness and hence was not linked to the attainment of the students (Fleming, et al., 2016).

In order to learn science students, need to be able to read, write and do mathematics. So, it is important to give due consideration to the literature published that could indicate that there are domain specific links between WM and attainment. There is evidence to suggest that domain specific WM training improves attainment (Peng & Swanson, 2022). There are many studies investigating the link between WM and the attainment of students with learning disabilities relating to reading, writing and mathematics, and WM and attainment in mathematics and English. However, there is very little published literature in the domain of science and WM. This part of the literature shines a spotlight on the gap in the literature on WM and its' link to secondary school Science attainment. Contradicting this idea were the findings of a meta-analysis the conclusions of which pointed towards the strategy of students writing about subject material in the subjects of Science, Mathematics and Social Sciences increased their attainment with no link at all being made to WM (Graham, et al., 2020).

WM is vital for reading and writing. Working memory tests that include processing and verbal storage are good predictors for reading comprehension. In addition, WM tests that include maths processing and verbal storage are good predictors of reading comprehension. However, the predictive effect is to some degree domain specific. (Daneman & Carpenter, 1980; Daneman & Merickle, 1996). The writing ability of people is linked to their WM (Swanson & Berninger, 1996). Furthermore, WM is also used as a common resource for planning, translating, and reviewing during writing tasks (Kellogg, 2001). Verbal WM is required for the formulating sentences within the brain before writing them and visual WM is used in the planning part of writing the parts of the prose that involved imagery (Kellogg, 2001). So the literature strongly suggests that WM is vital for reading and writing and hence learning.

In addition, studies have also suggested that the phonological loop is also involved in the planning process of writing (Olive, 2004). In direct contrast it was found that only the executive part of the WM that had a large role in predicting writing ability. The executive part of the WM predicted the following aspects of writing ability; planning, translating, revision, higher-order microstructure skills and vocabulary. However, two other parts of the WM ie visuo-spatial sketch pad and the phonological loop did not predict any of the writing skills (Vanderberg & Swanson, 2007). This may indicate that WM might not in its' entirety be as integral to writing ability. However, there is some evidence that suggests that WM is not linked to reading comprehension or writing ability. There is evidence that points towards extended text reading being a predictor of depth of reading comprehension (Duncan, et al., 2016). Futhermore, there is evidence that supports student IQ, understanding of grammar and ability to read words as predictors of narrative writing (Olinghouse, 2008).

In addition to which, when looking at the attentional and executive functioning in writing. Planning (to a greater extent) and revision both use more of the WM than translation. In addition there was an interesting observation made from part of the study by Olive and Kellogg 2002 that young children pause when transcribing so they can plan what to write next. The transcibing action in children takes up significant amount of WM capacity so in order to plan what to write next the children have to stop transcribing. This indicates that the WM that is involved in planning what to write and can only be fully accessed when transcribing stops. (Olive, 2004). The literature supports the idea that composing text places large demands on visual and verbal WM and to a lesser extent spatial WM. (Olive, et al., 2008). Furthermore, once students have composed and completed a piece of writing a visual representation of the text seems to be stored in visual WM (Le Bigot, et al., 2012). However, the embedded-processes model indicates that writing also requires a large amount of the LTM to be activated; writing is not solely taxing WM (Cowan, 2014). Hence, in students with weak or poor writing skills; could be caused by not being able to activate the correct information in the LTM rather than WM deficits (Fenesi, et al., 2015).

A possible link has been established between WM capacity and reading and writing (Kellogg, 2001; Olive, et al., 2008). The evidence points towards planning, forming grammatically correct sentences and then physically writing the words all require WM. One might conclude that WM is needed for spelling an important part of planning and writing (Service & Turpeinen, 2001). This indicates that planning requires both visuospatial and verbal WM, with also EF needed for all of the parts of writing. No matter how good a person gets at writing it will never become a fully automatic process because thinking of ideas and what to write is always needed and always uses WM (Dehn, 2008). In contradiction to this stance there is some evidence to support students writing about subject material in the subjects of Science, Mathematics and Social Sciences increased their attainment with no link at all being made to WM (Graham, et al., 2020).

Maths anxiety is a well-researched area where anxiety causes the WM to be overloaded and hence people cannot complete maths tasks at all well. This would clearly affect their learning of mathematics. Mathematics is a key skill to be able to learn Science and hence would have an impact on KS3 Science attainment. A link may have been established between WM load increasing when students are doing more complex arithmetic. Students with high mathematics anxiety will do the problems as quickly as possible even if the answers are wrong. This is thought to be because the participants want to finish the test as quickly as possible so that the anxiety ends (Faust, et al., 1996). If students use this as a strategy to manage their anxiety this will have an impact on the quality of class work and homework (Ashcraft & Krause, 2007). If the students with Mathematics anxiety in KS3 Science classes rush work involving arithmetic and other mathematical tasks (e.g., devising the correct scale for a graph) then this will have an impact their Science attainment. Hence, science subject specific activities to develop WM would help support students with Mathematics anxiety in their Science lessons and perhaps with far transfer effects in their Mathematics lessons too. There is evidence to suggest WM is required for mathematics learning to take place with a relationship between WM and mathematical performance being evidenced (Berkowitz, Edelsbrunner, & Stern, 2022) On the other hand, there is research that suggests that Maths anxiety is not linked to WM but instead is attributed to teaching strategies, parent and family attitudes to learning maths, in addition to fear of failure and lack of confidence (Finlayson, 2014).

2.6 Working Memory Can Be Improved

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 32 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of working memory can be improved.

This section of literature review looks at the theory and findings of the key construct working memory can be developed (has neuroplasticity). This key construct can be further defined as actions that an individual human undertakes may change the speed or size of their WM. The literature on the neuroplasticity of WM and the efficacy of WM training is discussed. As one of the principles behind this doctoral research is that WM of secondary school ages students does have plasticity and can improved with training. There are some researchers of memory who believe that WM has a fixed capacity by either the number of facts held at once or how long information can be kept in the WM without being rehearsed (Cowan, 2014). However, despite scepticism such as this, there are many research teams investigating if WM Training can increase WM capacity or function. Since the first research into learning and memory the idea of the brain having plasticity has been common. However, the ground breaking research of Hebb in the early 1960s, his contemporaries and those neuroscientists who followed in their footsteps; repeatedly stated that brain plasticity was linked to learning and memory and was only present at the embryonic and infant stages of development (Cooper, 2005).

Thirty years ago, neuroscientists thought that the brain was fixed after childhood and that no new neuronal connections were made, no reinforcement of old connections was made and no new neurones were made. In the past 30 years the research in the field of neuroscience has provided evidence that adult brains have plasticity and hence can make new neurones, new neuronal connections and reinforce old connections hence leading to the brain being able to adapt and evolve to a changing external environment (Ricard, 2007). This breakthrough in cognitive and neural psychology has led to the idea of brain training that has been popular in computer games and apps in recent years. However, some are sceptics of neuroplasticity to be the explanation for improvements that maybe, able to be explained by other branches of psychology (Farina, 2017)

The idea that the brain and hence intelligence is not fixed and there are lifestyle choices that can influence the brain has attracted a lot of attention. There have been many different studies to demonstrate the plasticity of the brain and what can influence this plasticity. Factors that may have been proven to have had an impact on the connections in the brain and in some cases, size of the brain are imagination, mental rehearsal, stroke patients recovering using a specific technique, the thoughts people have, meditation and exercise (McNeil, 2009). “Attention is key to plasticity of the brain” McNeil refers in this section of his book to research of Michael Merzenich and his brain plasticity training to support this claim (McNeil, 2009, p.156). There is some critique of brain training methods for example in sports where some researchers claim that there is little evidence of general transfer (Renshaw, et al., 2019).

There is a wide range of activities that have been used in research into training WM. These include physical activity (Diamond & Ling, 2016) mindfulness (Chambers, et al., 2008; Diamond & Ling, 2016; Jha, Stanley, et al., 2010), music (Lee, et al., 2007), mental arithmetic (Lee, et al., 2007) as well as the greatly favoured computer training both non-adaptive and adaptive (e.g., Diamond & Ling, 2016; Westerburg & Klinberg, 2007). Furthermore, aspects of WM training research have been conducted on a wide range of ages from 11 months (Wass, et al., 2011) to 80 years old and over (Buschkuehl, et al., 2008). There is other WM training research that has a focus on increasing intelligence (Au, et al., 2015; Jausovec & Jausovec, 2012) and other evidence that suggests that WM decrease due to such wide-ranging causes as dissonance (Martinie, et al., 2010) and military pre-deployment stress (Jha, et al., 2010). On the other hand, there are some memory researchers who state that WM is fixed and there is another mechanism occurring (Cowan, 2014). However, more recent research has evidenced the brain changes after typically developing children underwent WM training (Jones, Adlam, Benattayallah, & Milton, 2022).

One might conclude that WM training of various methods improves WM and in some cases attention. However, there is very narrow transfer and the evidence indicates that improvements cannot be used to increase attainment at school as they are not domain specific. The longer the participants take part in these training programmes and are practicing the mindfulness or physical exercise the better the reported improvement in WM (EF). However, participants using the computerised training programme n-back found that longer training periods did not improve WM (EF) any more than shorter training periods. Although the evidence tends towards there being an optimum training time (Diamond & Ling, 2016). On the other hand, there is some evidence that doing specific types of physical exercise have been shown to improve EF (WM) in a domain specific manner that may supports students' attainment in school (Affes, et al., 2021).

Furthermore, in 1996 the visuospatial sketch pad was linked to the production of physical movement of the body (Dehn, 2008). There is a good chance however that the research that found physical exercise improved EF (WM) may have showed a correlation rather than causation. There are a great many other factors that could be having a positive impact on EF (WM) including healthy eating, the complex cognitive demand of playing some team games, individuals being in "the flow" and hence mindful during their physical exercise (Diamond & Ling, 2016). One might conclude from the literature that the largest improvement in EF (WM) in this review is from students or participants that had the poorest EF (WM) at the start. On the other hand, the evidence points towards these improvements not being sustained over a long period of time. One may conclude from the literature that EF (WM) will start to decline again if the training is not maintained (Diamond & Ling, 2016). There is strong evidence that EF (WM) can be improved; the focus should now be on what interventions and training programmes have the biggest effects (Diamond & Ling, 2016).

Interestingly there is some evidence that demonstrates WM training has significant increases in intelligence (Au, et al., 2015; Jausovec & Jausovec, 2012). However, it has also been questioned that the studies included in a meta-analysis did not have active controls. Hence, the Hawthorne effect might well account for the bigger effect size. If this was considered, after all the studies without active controls were excluded the effect size becomes smaller and loses significance (Melby-Lervag & Hulme, 2016). A reply to the critique made by the authors Au et al answers the criticisms levelled against their meta-analysis and claiming that WM training does significantly increase intelligence (Au, et al., 2016). Demonstrating that the studies without active control do not show clear evidence of the Hawthorne effect and the impact of their not being active controls is at best ambiguous. There are clearly other confounding variables influencing the results that are shown in the active and passive control groups of the studies. However, these results do not impact on the overall effect size of WM training on measures of fluid intelligence (Gf) (Au, et al., 2016). Hence, the evidence implies that WM training may improve Gf.

The age range of the literature published on WM training is vast from 11 months to over 80 years old (Buschkuehl, et al., 2008). The evidence would suggest that Children as young as 11 months old (Wass, et al., 2011) show increases in attentional control and WM after undergoing computer based and non-computerised training (Wass, 2015). Adults over the age of 60 years were exposed to a range of WM training techniques; the evidence seems to indicate that all forms of training significantly increased performance in the actual task (requiring WM) and had near transfer effects, there was a smaller significant increase in far transfer effects. The findings and theory of this study referring to far transfer effects helped to inform research question c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

However these findings may not be valid with no active control and the over reliance on small studies publishing statistically significant positive data where unpublished studies that yielded no statistically signficant results remain unpublished (Melby-Lervag & Hulme, 2016). Old-old adults are characterised as those who are a minimum 80 years old. One might conclude that old-old adults show an increase in memory especially of visual working memory and a small increase in visual episodic memory after WM training. But these increases were shown straight after the training only. There was no difference in the memory measures one year after training. This may demonstrate that in order to maintain the brain plasticity, working memory training must be done for a set amount of time yet to be determined. (Buschkuehl, et al., 2008). This demonstrates that further research needs to be undertaken. Future research that has WM training as a long-term research study over months or years would be able to illuminate an optimum time frame of training for WM.

There are a wide range of factors that seem to have a negative impact on WM. These include lack of sleep, drinking alcohol, dissonance, anxiety, and stress (e.g Diamond, 2010; Martinie, et al., 2010; Hassed & Chambers, 2014). The evidence indicates that the stress that military personnel experience during pre-deployment preparation causes a decrease in WM this does not improve with a small amount of mindfulness training (Jha, et al., 2010). Dissonance is the experience of having the choice of whether or not to do a task that you do not agree with. Dissonance has a negative impact on WM. In a high load memory task people perform worse when exposed to the dissonance condition. The indicates that the dissonance is taking up some of the WM capacity leaving less for the high memory load task (Martinie, et al., 2010). On the other hand, there is some evidence to suggest that mindfulness training can protect individuals from stress affecting their WM (Banks, et al., 2015).

The research discussed shows many and varied forms of WM training seem to increase WM capacity. However, it is still a controversial issue; some believe it is not possible to improve WM capacity. The hypothesis has been postulated that WM capacity cannot be improved so efficiency of processing and strategy use for interventions is what appears to have the impact and increases WM function. Interventions may demonstrate an impact and an emphasis on LTM, WM and STM as there is overlap between all of them then there should be a positive impact on WM even if that was not the initial aim (Cowan, 2014; Dehn, 2008). The research into WM still, has not clarified the ambiguity as to whether WM training is improving WM capacity or improving the efficiency of WM by the learning of memory strategies (Randall & Tyldesley, 2016). Furthermore, there are some researchers who think that WM capacity is fixed and that there are other mechanisms occurring to allow WM to access LTM (Cowan, 2014). The theory from some of that does literature support WM neuroplasticity helped to shaped the approach to the study to measure WM before and after the study, using a test that measured the constructs of WM that were part of the Baddeley and Hitch model that is being used for the study. This also enabled the overarching research question and research question a. to be formulated. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students? What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

The research of Kandel and others over the past 30 years, finding the physical evidence of emotions, memory and learning within the brain (Dobbs, 2007; Kandel, 2005) seems to leave all philosophers of the mind; with nothing short of a paradigm shift in the mind being a definite physical entity. This broadly supports the idea of WM physically changing as a result of external stimuli. However, Kandel himself states in an interview that the big areas of research are those which will demonstrate how different areas of the brain that contain different parts of the memory physically interact with one another (Kandel, 2005). This includes how WM physically interacts with LTM; it has simply not been discovered yet (Kandel, 2005) . Research in 2016 however, suggested that brain training increased the efficiency of the neuronal gatekeeper network in the prefrontal lobe that is associated with the WM (Smicker, et al., 2016). This supports the approach I had to the study to have a model of WM that was well placed to be used in a secondary school setting. All the physical brain constructs of WM are still not clear and completing brain imaging on 180 students would be unethical and the cost prohibitive.

However, it could be argued that WM training enables individuals to increase the efficiency of chunks of information being committed to LTM from WM; hence freeing up capacity in the WM. This is currently in unpublished work but is cited here (Cowan, 2014). There is as mentioned in the paragraph before research in 2016 that has suggested that brain training increased the efficiency of the neuronal gatekeeper network in the prefrontal lobe that is associated with the WM (Smicker, et al., 2016). Alternatively it might be possible to train students to better use their current WM. It appears to be possible to train critical thinking ability (Halpern, 1998) and there is some evidence to support the idea that it is possible to train memorisation to an expert level (Ericsson, et al., 2004). This aside there is strong evidence for WM training improving WM.

2.7 Working Memory is an Important Differentiator of Students' Attainment

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 33 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of Working Memory being an important differentiator of student's attainment.

One of the seven key constructs of this study is that increasing working memory increases attainment. This means that if a student's WM increases, they are able to increase their ability to learn (see Figure 11) and hence their attainment in lessons will increase.

This aim of this doctorate research (and the overarching research question) is to find out if activities to develop WM that I have developed for KS3 Science lessons are effective in increasing WM and hence demonstrates efficacy in increasing Science attainment in KS3 students. The antecedent for this research was as a teacher-researcher to find a teaching strategy that increases attainment in Science in all KS3 students. Hence the relationship between the function of a student's WM and their attainment underpins the research undertaken for this thesis.

In this section the published literature and research that demonstrates that the WM of students differentiates their attainment at school is reviewed and considered. In order to formulate strong arguments in the discussion and conclusion Chapters of the dissertation it is important to establish WM as a recognised differentiator of student attainment within the published literature. This section of the literature review demonstrates the wealth of national and international literature that is available on the subject of Working Memory (WM) as a differentiator of student learning and attainment. On the other hand, this Section also considers if WM is a necessary and sufficient differentiator. There is a good deal of research that seems to support the fact those students with WM deficits may have other learning disabilities and are less likely to attain highly at school.

The Baddeley and Hitch model of WM is used in classroom research; however, many teachers are unaware of what WM is or its' impact on students' ability to concentrate and retain information. WM is differentiating students implicitly and without the understanding of their teachers. Students who are underachieving in the classroom may have a WM deficit that is part of a broader learning difference or could be a student with solely an undiagnosed WM deficit (Alloway & Gathercole, 2009) and the evidence suggests that in students with autism their WM is a predictor for their learning outcomes (Kim & Kasari, 2023).The evidence tends towards students with very minor learning disabilities have a phonological WM deficit, whereas students with minor to moderate learning disabilities have WM deficits in all constructs of WM (Henry, 2001). On the other hand, how, studies measure WM may differ and how studies categorise learning disabilities may be different. There could be a degree of subjectivity meaning that any conclusion drawn can only at best be tentative.

There is some evidence to suggest that student performance on computerised WM testing software predicts students who go on to make poor academic progress (Alloway & Gathercole, 2009). However, this should be treated with some scepticism as the software was being developed and marketed by the authors of the research. The authors were advocating its use as a tool to identify students for possible intervention and support with their academic progress. Potentially what could be perceived as a necessary and sufficient differentiator; could be just being marketed effectively and commercialised in a worldwide market estimated to be worth billions of pounds worldwide and growing (Unknown, 2018).

There has been some evidence suggesting that WM is different in people due to physiological (or biological) differences. There may be a link between early years students with chromosomal disorders having attentional control/WM deficits that go on to lead to more complex learning disabilities (Wass, 2015) as the students get to school age and beyond. Evidence tends towards students with learning disabilities have less blood going to the prefrontal cortex (where part of the WM is located) compared to normal students (Packiam Alloway & Alloway, 2015). On the other hand, and in direct contrast; dyslexic students (who have a weaker WM as part of their learning disability) may have more blood going to the prefrontal cortex compared to normal students (Shaywitz, et al., 2003).

The CE in the Baddeley and Hitch model of WM is an EF (Baddeley, et al., 2001). EF has, many researchers believe a strong overlap with WM (Diamond, 2011; Friedman, et al., 2006; Yeniad, et al., 2013). So, it is important to include studies that show EF as an important differentiator of student learning and attainment. Furthermore, many different learning disabilities have a WM deficit as an aspect of their difference (Packiam Alloway & Alloway, 2015). Particularly EF deficit and verbal WM deficit, some researchers have attributed this to a WM capacity deficit whereas others state that there is a lack of learned strategies in students with learning disabilities (Dehn, 2008). Most researchers agree that the individual differences in peoples' WM can mostly be contributed to the processing ability of the central executive (Dehn, 2008).

There is evidence that WM has a capacity which can be used for storage and processing. However, there can be too much demand on storage and hence processing of language (e.g., information given verbally) cannot occur. Equally if the WM processing efficiency is weak the overall performance of the individual WM will have a negative impact on their ability to comprehend reading and compose writing (Just & Carpenter, 1992). However, as a person gets better at a particular cognitive task the processing becomes more automatic and less processing is needed so there is more capacity in WM to use along with this task or alongside this task. This tends towards people who have become better at a cognitive task may have done so because they have developed a larger WM capacity as a result of their practicing (Daneman & Carpenter, 1980).

Conversely at the other end of the ability scale; evidence tends towards students who have been nominated as Gifted and Talented (G & T) when tested were shown to have a significantly greater WM. Normally teachers are not able to discern explicitly the students WM capacity, they use the students' achievement. Hence, testing the WM of teacher nominated G & T students and finding these students do have higher WM scores is evidence that supports the idea of WM having an impact on student achievement and other characteristics that teachers look for in Gifted and Talented students such as reading comprehension and verbal abilities. (Kornmann, et al., 2015). However, other research has shown that when including WM measures in IQ tests for Gifted and Talented students the WM part correlates strongly with the reading comprehension outcomes but not the Mathematics (McGowan, et al., 2016). Furthermore, there is evidence to suggest that WM is a predictor of reading ability and literacy levels in primary school students (Bardack, et al., 2023).

There is a well-established hypothesis of WM as a differentiator of mathematics learning and attainment. There is evidence to support the idea that students who have dyscalculia have a weak WM due to poorer functioning prefrontal cortex (Packiam Alloway & Alloway, 2015). Word maths problems require a lot more WM capacity and processing then numerically presented ones. Young students in pre-school and Early Years seem to rely more heavily on their visuospatial WM to do Maths compared to older students; and the verbal WM is used more with Maths problems unless the problems are very complex then students may revert back to using visuo-spatial WM (Carden & Cline, 2015; Holmes & Adams, 2006). This is now becoming a focus of some Educational Psychologists and their research. The aim of the research is to ensure that students have strategies to use the visuo-spatial WM to solve maths problems (Carden & Cline, 2015). On the other hand, just because an increasing number of education researchers are concluding WM is a differentiator this does not necessarily make it a sufficient differentiator. For example, there is evidence that suggests that WM does not correlate with mathematics in G & T students (McGowan, et al., 2016); furthermore, a meta-analysis tended towards the conclusion that WM was a better differentiator of students with poorer mathematical skills than other ability students (Peng, et al., 2015).

However, the evidence strongly suggests that WM (the EF function of WM) is needed at all ages in order for students to do Maths. EF includes the ability to inhibit irrelevant information in mathematics questions in order to access the correct mathematical skill for LTM to complete the questions successively. Hence, not being able to inhibit information effectively would have an impact on mathematics attainment (Fenesi, et al., 2015). However, in students with ADHD or other learning disabilities with WM EF deficits; their ability to be able to complete a maths question that contained irrelevant information was not as good (Dehn, 2008). The EF of school students who were full term at birth compared to students who were preterm at birth also appears to be a differentiator in learning and attainment. The ability to switch task effectively might not have fully developed in the pre-term children. On the other hand, Children who are rated highly for thinking before acting and sitting still by their parents (i.e., were well behaved) did better in the maths tests this could be because they can access the teaching more effectively (Matthews & Adlam, 2015).

The evidence indicates that WM is a differentiator of the National Curriculum-based Mathematical skills and attainment in Swedish 8–9-year-olds and Year 5 students in England. (Holmes & Adams, 2006; Nyroos & Wiklund-Horngvist, 2011). Academic achievement in geometry (in 9-year-olds) seems to have a large dependency on WM this includes both visuospatial and verbal WM regardless of intelligence. Intuitive geometry is closely related to fluid intelligence and intuitive geometry is not linked to academic achievement in geometry (Giofre, et al., 2014). However, WM and geometry in education is not a largely researched area.

There is a great deal of evidence that shows that the WM (EF parts of WM) can be linked to academic attainment. WM updating EF is a good predictor of academic attainment, especially when using numerical based activities (Lechuga, et al., 2014). There is evidence to indicate that verbal WM is a differentiator for reading level and reading comprehension (Dehn, 2008; Pimperton & Nation, 2014; Swanson, et al., 2009). However, a small proportion of people also present with behaviours linked to overall WM weakness which attribute to a domain general WM weakness (Pimperton & Nation, 2014). Conversely, evidence also points towards Verbal WM, WMEF and LTM as all differentiators of reading comprehension (Berninger, et al., 2010). Students with a RD (reading difficulty) could find it difficult to monitor and retrieve information especially when information is presented within sentences. This weakness may be in the phonological loop and the executive system and seems to continue with age. (Swanson, et al., 2009). However, it is important to state that the impact visuo-spatial WM has on reading is not as well researched. In those students with reading disabilities their underachievement could be explained by lack of knowledge or use of verbal rehearsal strategies or lack of articulation speed (Dehn, 2008). So, these findings could be due to other learning differences; with this level of contradictory evidence, one might conclude that WM may not be justified as differentiator. Furthermore, there is also evidence that student characteristics including gender, being able to plan the writing in advance, IQ, and fluidity of hand writing are differentiators of writing ability (Olinghouse, 2008).

WM capacity may be a differentiator of students reading and writing attainment evidence tends towards students with poorer reading skills are the students with the poorer working memory (Berninger, et al., 2010). The evidence supports the hypothesis of there being a relationship between STM, WM or IQ. (Swanson, et al., 2009). On the other hand, this research was done on the premise that WM and STM work independently of each other (Engle, et al., 1999). This makes these conclusions more tentative in the context of this doctoral research given the argument put forward about using the Baddeley and Hitch Model (STM is part of the WM) as the predominant model of working memory explained previously in this literature review. In addition to which; other evidence tends towards age, gender, and frequency of reading traditional texts is a differentiator of reading ability in adolescents (Duncan, et al., 2016).

One might also conclude that the ability of students to read and write is differentiated by WM. WM tests that include processing and verbal storage (both linked to WM) seem to be good predictors for students to be able to comprehend text (Swanson & Berninger, 1996). However, the predictive effect of WM could be to some degree domain specific. (Daneman & Carpenter, 1980; Daneman & Merickle, 1996). The embedded-processes model shows that writing could also requires a large amount of the LTM to be activated; writing is not solely taxing WM (Cowan, 2014). Hence, in students with weak or poor writing skills this could be caused by not being able to activate the correct information in the LTM rather than just WM deficits (Fenesi, et al., 2015).

Narrative writing also presents a large challenge to low reading comprehenders. Writing narratives may be cognitively more demanding to write than descriptions. Narratives could overload WM. In the WM updating task, poor comprehenders seemed to perform worse than good comprehenders (Carretti, et al., 2013). Evidence seems to suggest that a good WM is important to learn vocabulary, understanding language including understanding stories and for academic attainment in general. Students with language impairments could struggle in part because of a weak

WM in attention, processing, and storage of information (Boudreau & Contanza-Smith, 2011; Boudreau & Contanza-Smith, 2011). Hence supporting the argument that WM could be a differentiator of attainment.

There have been many studies demonstrating that WM is the differentiator of attainment for students with learning disabilities in Reading, Writing and Mathematics (Swanson & Berninger, 1996; Peng & Fuchs, 2016) and also, a number of research teams that have investigated the differentiating effect of WM on attainment in Mathematics and English (e.g., Gathercole, et al., 2004). In addition, it has also been demonstrated that WM tests that include maths processing and verbal storage are good predictors of reading comprehension. (Swanson & Berninger, 1996). Broader spectrum learning disabilities will have WM deficits that are more domain general. On the other hand, students with moderate disabilities have the largest weakness in numerical WM. However, this may be due to the lack of mathematical knowledge in LTM rather than a WM deficit (Peng & Fuchs, 2016).

WM seems to be a differentiator of academic performance in Mathematics, English and Science in England (Alloway & Gathercole, 2009; Gathercole, et al., 2004; Packiam Alloway, et al., 2010). On the other hand, a closer look at the research shows that SATS tests on KS1 (6–7-year-olds) students did not do Science tests. Moreover, the SATS tests on KS3 (13–14-year-olds) English Literature results were independent of WM (Gathercole, et al., 2004). However, there is evidence that tends towards EF being a differentiator of Early Science education (Gropen, et al., 2011). This indicates that there are very few studies that demonstrate that WM is a differentiator of academic attainment in the domain of Science in particular in Secondary School aged students.

There seems to be a relationship between cognitive styles, WM, and academic attainment. In particular within the cognitive styles research the evidence tends towards WM being a differentiator for academic attainment in Science (Packiam Alloway, et al., 2010; Riding, et al., 2003). There appears to be a link between students with a verbaliser cognitive style and high WM having good Science attainment (Packiam Alloway, et al., 2010). The evidence implies that WM was a significant differentiator of Year 8 (12–13-year-olds) students' Science attainment (Riding, et al., 2003). On the other hand, the research considers in detail different types of cognitive styles that students adopt when learning. The cognitive styles are constructs of the researchers in this specific study and in the research considered the cognitive styles are different for different studies. This makes this evidence more tentative.

If WM is a differentiator of attainment, then one might conclude that at this current time the best tools a teacher has; is to differentiate for these students. Differentiation to support students with WM deficit has been advocated within the published literature (e.g., Alloway & Gathercole, 2009; Cowan, 2014; Dehn, 2008; Packiam Alloway & Alloway, 2015). If WM deficits or natural variability leads to some students not fulfilling their potential then it is a necessary differentiator to focus on as a teacher. Hence, it is important that classroom activities are closely analysed for the different loads they make on the WM storage and processing. Teachers should simplify language used in text (differentiated reading materials which are used as one of the activities to develop WM this research doctorate is based on) and for teachers to modify the number and complexity of instructions given verbally in the classroom. Other suggestions for supporting students with weak WM are: chunking information and providing visual scaffolding (Boudreau & Contanza-Smith, 2011). It is important for students with a WM deficit to practice skills (for example times tables) so that there is automaticity of those skills. This then releases the demand on the WM and means that the processing and storage of information in WM is more efficient so information can be placed in the LTM more efficiently. The use of different memory and metacognition strategies is as a way to support students with speech and or language difficulties (but would also be applicable to students with just a weak WM) (Boudreau & Contanza-Smith, 2011).

This Section of the literature review clearly demonstrates that there is a wealth of literature published both nationally and internationally that has WM as a differentiator of attainment. The findings and theory in this literature have helped to develop the overarching research question and research questions a. and b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions? What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?

However, there are a number of key research conclusions that are muddied by a number of confounding variables sometimes putting the differentiating ability of WM into question. On balance the wealth of research seems to demonstrate that WM is a sufficient differentiator.

2.8 Working Memory Can Be Improved in School Aged Students

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 34 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of Working Memory can be improved in school aged students.

One of the seven key constructs covered in this literature review is people who complete certain activities can increase their working memory. This section will demonstrate that the findings and theory in the literature support the construct that people completing WM training on specific computer programmes or other types of activities could increase their WM.

There is as we have seen in the previous section extensive research published in the literature about WM being a differentiator of attainment. In addition, there is a good number of studies that demonstrate that WM has plasticity. This Section narrows down WM training in the literature to those studies that have intended to increase the WM function of school age students. The following part of the review includes WM training studies that have intended to increase the WM function of school age students and finally, studies that have been conducted using school age students within a school. This Section is important in establishing that the theory of WM having neuroplasticity is based in evidence. The thesis research is underpinned by the principle that KS3 students WM can be improved by using the activities that have I have developed to increase WM. Any increase in students' WM may in turn increase the Science attainment of those students.

The types of WM training are as diverse as the types of people accessing WM training. However, due to the great interest in WM and its' obvious link to learning, several research teams have turned their attention to WM training in school age children for example (Apter, 2012; Dunning, et al., 2013; Fernandez-Molina, et al., 2015; Rueda, et al., 2012; St Clair-Thompson, et al., 2010). This part of the literature review examines the research which is specific to school age students. However, there is a caveat that the research discussed here only includes WM training which has occurred at home, or at school administered by researchers or administered by teachers but the students have no support from the teachers or the training is delivered by teachers but not as part of the regular curriculum. Hence, the research discussed here, is of short-term interventions with students of school age. This is to ensure that there is clarification about how the vast majority of WM training is being conducted with school age students. This in turn will show the stark difference between the current research focus of published literature compared to the domain specific classroom-based WM training implicit within lesson plans (which is the focus of this thesis' research). The next Section (2.9) of the literature review will address directly the published literature that is conducted specifically in a school setting, by teachers within the normal curriculum.

Researchers of WM in school age students often use the Baddeley and Hitch model of WM. This literature supported my approach of using the Baddeley and Hitch model of WM for this study; using it as a pivotal part of the theoretical framework where learning and hence attainment may increase in school aged students see Figures 11, 12 and 13. New information taxing the WM can increase the size or efficiency of WM components in the brain. WM training seems to have the biggest impact for those students who start out with the lowest WM (Diamond & Ling, 2016; Holmes, et al., 2009; Klinberg, 2010; Cowan, 2014). It has been established that school age students with a large range of learning disabilities appear to also have low WM as a part of the difficulties they experience. (Alloway & Gathercole, 2009; Packiam Alloway & Alloway, 2015). In addition to which, evidence suggests that WM training increases WM and fluid intelligence; but does not impact on motivational factors (Vernucci, Canet-Juric, Lorena, & Richards, 2023). This latter point will be discussed in relation to the perception data in the discussion. Furthermore, there is a range of national and international literature that is focused on WM training in schools or with school age students including those with learning disabilities. This research is implying that it could be possible to improve the WM of students e.g., (Boudreau & Contanza-Smith, 2011; Lohaugen, et al., 2011; Malekpour & Aghababei, 2013; Van der Molen, et al., 2010).

"The observed training effects suggest that working memory training could be used as a remediating intervention for individuals for whom low working memory capacity is a limiting factor for academic performance..." (Klinberg, 2010, p. 322). More recently there has been evidence to suggest that game-based WM training in a school setting, improves WM and demonstrates domain specific transfer (Johann & Karbach, 2020).

The theory and findings from this literature supports the approach of developing a set of activities to develop WM and hence improve attainment. The literature also shaped the intervention to be a naturalistic experimental model as the literature supports interventions with school-age students in school settings. This led to the development of the overarching research question and research questions a and b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students? What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions? What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

Computerised training of WM is becoming very popular. WM can either be adaptive or non-adaptive. The WM training that does not state if it is adaptive or is clearly non-adaptive (does not increase difficulty as the user engages with the programme) is addressed in this section of the literature review. Students between the age of 4 and 16 years old in a range of countries were exposed to computerised WM training. There is strong evidence to suggest that this WM training increased the WM of the students involved (Fernandez-Molina, et al., 2015; Malekpour & Aghababei, 2013; Rueda, et al., 2012; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010; Van de Sande, et al., 2016; Van der Molen, et al., 2010).

However, one group of authors' interpretation of the results was in terms of the computer programme on which the training was being delivered. The positive results are all in terms of being more independent and playing more games in this independent manner. (Van de Sande, et al., 2016). The positive impact on WM could just be students getting better at playing on a computer game. On the other hand, there is evidence to support playing WM games and number games with kindergarten aged students improved their WM but not their numeracy skills; whereas the control group saw an increase in numeracy skills (Ramani, et al., 2020)

When students who were five to eight years old who underwent the WM training on a commercially available programme called *Memory Booster.* The evidence suggests that the *Memory Booster* programme improved their phonological WM and WM CE; On the other hand, the authors also state that it is hard to discern if *Memory Booster* is having an impact on WM capacity or the strategies are making the WM more efficient (St Clair-Thompson, et al., 2010).

The evidence indicates that WM training also has an impact on 13- to 16-year-olds. When this age group of students was exposed to both adaptive and non-adaptive computerised WM training; both types of training seem to have had a positive impact on story recall, arithmetic, and visual STM. Furthermore; the non-adaptive training appears to increase visuo-spatial WM capacity (Van der Molen, et al., 2010)

Computerised adaptive WM training is the most common in the published literature. The training is considered adaptive if the activities that the students complete become progressively harder as the students become better at performing the activities. Furthermore, the adaptive computerised WM training is clearly accessible to these students because they consciously engage in the use of WM and in order to do this, they have to be fairly confident that they are going to be successful at the activity. This is where differentiation which enables work to be challenging and yet accessible is so important. (Apter, 2012). Studies using adaptive WM computerised training have been used with a wide range of age groups including both primary and secondary students. The published studies have included academically "normal" students as well as students who have a range of learning disabilities (Boudreau & Contanza-Smith, 2011; Dunning, et al., 2013; Holmes, Gathercole, & Dunning, 2009; Karbach, et al., 2015; Lohaugen, et al., 2011; Pascoe, et al., 2013; Van der Molen, et al., 2010). Furthermore, evidence suggests that adaptive computerised WM training Cogmed® has a greater impact on students with low WM (Spencer-Smith, et al., 2020).

The published literature points towards computerised WM training both adaptive and non-adaptive being able to increase the WM of students of school age. On the other hand, computerised adaptive WM training and its' effectiveness has been the subject of some debate and criticism including the size of studies being too small and the lack of an active control in some studies (Melby-Lervag & Hulme, 2016; Shipstead, , 2012). et al. This has brought into question the validity of the results for these programs. In particular the way of testing the different components of WM were criticised for not being rigorous or specific enough and also again the lack of active control groups (Apter, 2012).

WM training programs such as CogMed® and Jungle Memory are also both time consuming and economically very expensive (Apter, 2012). It is also important to note that to administer CogMed® training an individual also has to be trained to be a mentor to those students undertaking the training. There is some indication from the literature that it is not the computerised training that improves the students' WM but the mentoring experienced by the students (de Jong 2014; Diamond & Ling, 2016). Furthermore, Cowan does not go as far as a critique of WM training however warns that researchers should be: "wary..."as there is "…rudimentary …evidence in a difficult field and the plethora of companies selling working memory training exercises." (Cowan, 2014, p.213).

Concerns have been raised by some cognitive psychologists that the vast majority of the WM training is using computer-based programmes. This could lead to WM training not reaching its full potential. The way the WM training is delivered could be one of the reasons why the evidence is not as firm or valid for WM training as it could be (Randall & Tyldesley, 2016). Furthermore, as many of these WM training programs are computerised and are used in studies and in schools as intervention materials to increase WM over a short period of time for example a few days or weeks it is difficult to have an significant impact on attainment. The difficulty with computerised WM training is that there appears to be little if no near or far transfer effect. This makes WM training in a school setting hard to justify particularly in our current national and international climate of target driven education. On the contrary Studer-Luethi, Toermaenen, Margelisch, Hogrefe, & Perrig found that maths performance improved when school aged student underwent WM training (Studer-Luethi, Toermaenen, Margelisch, Hogrefe, & Perrig, 2022). But, there is a lack of any literature that includes WM training with large numbers of students over a long period of time. I found only a very small numer of studies that had been conducted over an entire academic year; one of these demonstrated numeracy and WM gains in primary school students (Muñez, et al., 2023). But having more longitudinal studies would benefit education practioners by demonstrating if there are possible near and far transfer effects or indeed lack there of. The findings and theory from the literature on computer based WM training made me steer clear of computer based training activities. The evidence suggests that computer based training can improve WM but these are short term intervention studies; for example Wiest et al. demonstrated an increase in WM after computer based training, but the sample size was n=8 (Wiest, Wong, Bacon, Rosales, & Wiest, 2020).

However, the fact that many of the computer based training programmes were adaptive informed my own activities to develop WM. The listening, reading and writing activities were all adaptive in at least one aspect of their delivery. This was important part of the study as it would ensure that the WM of the students would be continually taxed throughout the 2 year period of the naturalistic experimental study.

However, there are some studies that have already been referred to earlier; that have sort to address the issue of transfer effects due to WM training. The evidence indicates in each of these studies that WM increased due to WM training. However no near transfer to literacy skills was found in the classroom (Van de Sande, et al., 2016). Nor was there any far transfer found in test results in class using *Memory Booster* (St Clair-Thompson, et al., 2010). On the other hand, students with low WM appear to increase in their maths attainment after 6 months after WM training. (Holmes, et al., 2009). Other students who underwent WM training seem to have had an increased performance in the standardised reading test. But there was also no evidence that the adaptive WM training improves performance in the standardised math test (Karbach, et al., 2015) The biggest impact appears to be with those students whose pre-test had the lowest WM and reading score. This pattern of compensation saw the biggest compensation made with the lowest scoring pre-test WM students showed the biggest transfer effects (Karbach, et al., 2015).

The evidence suggests that interventions that have used WM (EF) training have seen improvements in academic achievement especially in the domain of language and reading. These improvements have been reported for healthy children and those with cognitive deficits and learning disabilities (Titz & Karbach, 2014). Titz & Karbach suggest after conducting their detailed meta-analysis that rather than using general WM (EF) training regimes a more appropriate approach would be domain-specific training (Titz & Karbach, 2014, p. 863). It is important to encourage students to use it in domain specific ways when applying their training or no far transfer or even near transfer will be evident (Dehn, 2008). There is some (but not a great deal of) literature that includes alongside WM training research analysis of transfer effects to domain specific areas of the curriculum.

The following domain specific study is particularly interesting because it uses students in 9–11-year bracket and teachers delivered the training programme in classrooms. The evidence indicates that training focused on WM and metacognitive processes in reading had a bigger impact than the training focused on WM and metacognitive processes in a listening group. However, this was still training that was separate to the normal curriculum delivered; on the other hand, it is domain specific and delivered by teachers in the classroom with a positive impact on attainment (Carretti, et al., 2014).

Furthermore, primary school age children from 8-10 years were given 8 hours of metacognition and WM training using the same materials as in the Carretti et al study 2014 (Carretti, et al. , 2014). There appeared to be evidence to show that student's arithmetic problem-solving skills improved. The impact of the WM training seems to be greater than the metacognition training. The students appear to have greater WM improvements than their arithmetic problem-solving skills. The evidence would also suggest that the group who did the training earliest in the school year also maintained the gains made in WM and metacognition after the training had finished (Cornoldi, et al., 2015).

Hence, supporting the need to for further classroom-based research over a long period of time. This would enable evidence to either support or challenge the findings of these studies. The only domain specific literature available which was conducted with secondary school students is specific to History. Students who did WM capacity training combined with reasoning skills training on a non-adaptive computer program appear to demonstrate an increase in the WM and reasoning skills of the students. These outcomes may also be used to increase attainment when delivering History to secondary school students (Aries, et al., 2015). This also appears to demonstrate that WM training can when used alongside domain specific skills have a transfer effect that will have an impact on attainment. Hence, it can be concluded that the evidence tends towards WM training having domain specific near and far transfer effects on school age students.

However, current research is being conducted with small samples so positive results could well be due to another factor or variable (Randall & Tyldesley, 2016) and any conclusions drawn using this literature can be only tentative at best. In addition to which, it is important to draw attention to the lack of the research in the Science domain specific area; and the lack of published literature that is researching WM training that is delivered as a regular part of the curriculum in day-to-day science lessons and its' near and far transfer effects on academic performance.

The findings and theory in the domain specific literature informed the study collecting quantitative and qualitative data. The studies where there were metacognition activities and reasoning skills as the alternative interventions made me reflect about a normal classroom situation. The students would be likely to be exposed to metacognition activities if they were explicitly completing activities to develop WM. This would mean a pragmatic mixed methods approach would enable a multi-layered approach to analysing the impact of the activities to develop WM including the near and transfer effects and changes in metacognition, and perception of memory and learning science. This in turn helped to shaped the research questions c, d, and e. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory and learning in Science compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

2.9 Working Memory Training within a School Setting

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 35 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review of Working Memory training with in a school setting.

One of the seven key constructs covered in this literature review is students completing specific activities in the classroom can increase the WM and hence increase (Science) attainment. This means that domain specific activities that students have to complete in every lesson (See

Chapter 3) can positively impact and hence increase the student's WM. Because the WM is required for learning (Figure 11), the increase in WM means the students find it easier to learn and their (Science) attainment increases. The last section narrowed down WM training in the literature to those studies that have intended to increase the WM function of school age students both in the laboratory and latterly within schools. This Section considers and discusses the research published specifically on WM training in the classroom, as part of the curriculum and delivered by teachers. This doctoral research is based on discovering if the activities designed to develop WM within Science lessons improve WM in KS3 students and hence their Science attainment. This section discusses the published research that supports this theory.

This section should clearly demonstrate that there are a very small range of studies published in the literature completed within a school setting, conducted by teachers as part of the curriculum. Hence, indicate the significant gap in domain specific WM training in Secondary School and specifically in KS3 Science.

There are very few studies where the WM training is delivered by teachers in a school setting. The next part of the literature review will layout the limited amount of domain specific and or WM training within classroom setting published research that is occurring in schools both nationally and internationally. This will reveal a gap in the research specifically for classroom-based WM training to improve attainment with KS3 students in Science.

The Science subject specific activities to develop WM are a form of brain training that occurs within the construct of a normal science lesson. The Science specific activities to develop working WM enable the demand made on the WM to increase throughout the academic year. Hence, the WM training within the research is adaptive. The hypothesis of the study is that Science specific activities to develop working WM increase the capacity, efficiency, and executive functioning of the WM due to the plasticity of the brain. The Science specific activities to develop WM would potentially have a greater impact on the capacity and executive functioning of the WM of adolescents. In adolescents the limbic system develops first whereas the development of the prefrontal cortex develops later and takes longer to finish its development.

The prefrontal cortex is believed to be the location of the executive functioning part of the brain and hence is the location of the executive function component of WM (Giedd, 2015; Packiam Alloway & Alloway, 2015). The fact it develops later and takes longer to mature means that it has a much higher level of plasticity for longer. So hypothetically students aged 11-25 would have a greater benefit of WM training then adults above the age of 25. However, as far back as nearly 25 years ago a critique was published of using neuroplasticity to influence what happens in education and in and hence in the classroom; with the counterargument of using cognitive psychology to inform pedagogical changes in the classroom (Bruer, 1997) using the evidence-based strategies such as retrieval practice (Adesope, Trevisan, & Sundararajan, 2017). The critique has continued into this millennia (Farina, 2017)with evidence that supports neuroscience not being able to transfer into effective teaching strategies and furthermore, an opinion that there was little evidence to support the efficacy of brain training research (Dougherty & Robey, 2018).

The findings and theory of this research and the lack of science specific research made me particularly interested in including collecting both qualitative and quantitative data to find out if far transfer effects were or were not present in my study. Using questions in the student interviews and the student questionnaires. This also enabled me to develop research question c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

There has been literature published on WM training research conducted within a school setting (Cunningham & Sood, 2016; Holmes & Gathercole, 2014; Rode, et al., 2014). Futhermore, there are a range of programmes that claim to increase the WM (can be referred to as EF in some research) of students from pre-school age to the age of nine years old. These programmes are:

- Tools of the Mind (Blair & Raver, 2014; Diamond & Ling, 2016)

- The Promoting Alternate Thinking Strategies (PATHS) a curriculum aimed at changing the challenging behaviour of students by developing EF including WM (Riggs, et al., 2006).
- Chicago School Readiness Project (CSRP) an effective intervention for pre-schoolers that improves self-regulation (Raver, et al., 2011) which involves the use of WM.
- Head Start REDI Intervention (Bierman, et al., 2008)

There is a programme for nursery aged (pre-school) children called Tools of the Mind. This programme was used in the classroom as part of classroom activities and when it was used for only an hour a day it seemed to demonstrate very small near transfer improvements in WM (EF). However, when integrated into the classroom activities as part of the normal routine of teaching much better WM (EF) far transfer effects appear to have been demonstrated (Blair & Raver, 2014; Diamond & Ling, 2016). In the United States the impact of the Head Start REDI intervention on students' EF including WM was investigated. This intervention was conducted by teachers in classrooms over the time frame of September to April. The intervention included a specially designed reading programme, sound games and positive behaviour management techniques. The WM of students did not improve (as measured by researchers) however other EFs did improve including attention set shifting and task orientation (linked to attention focus). There is evidence that both of these aspects of EF do have at least some overlap with WM. There is evidence that tends towards brain training and neuroscience in the classroom not being effective (Dougherty & Robey, 2018). However, the REDI intervention delivered by especially trained teachers in classrooms has not had a direct impact on WM (Bierman, et al., 2008).

Take10!® is a well-researched intervention which has integrated physical activities into class room activities in order to improve WM (EF) of students. Over a number of years this intervention appears to demonstrate a positive impact on student EF and could be contributing to better attainment. However as mentioned before there are many factors that could be impacting on student attainment (Diamond & Ling, 2016; Kibbe, et al., 2011). The improvements seen from such interventions as Tools of the Mind, Take10!® and CogMed® might well be due to the passion and commitment of the person or people running the intervention (Diamond & Ling, 2016). In addition to which, there is evidence that indicates Montessori educational philosophy increases the WM (EF) of students. However, all of these interventions or philosophies may well be delivered by people who are very passionate about the impact they can have with students. There is evidence to indicate that the more committed the people supporting the participants are then the more likely the intervention will succeed (Diamond & Ling, 2016).

There is also an alternative computerised training program called Operation Acquire Research Acumen (ARA) that claimed to increase students scientific thinking skills and increase their attention focus (Halpern, et al., 2012) however 5 years after its' launch Pearson Higher Education are no longer selling this product (Operation ARA). One can only speculate as to whether this is due to lack of efficacy or education budget cuts meaning there was no market for this product. However, literature has been published that has evidence that tends towards brain training not being effective (Dougherty & Robey, 2018)

Researchers have investigated if teacher led WM training would have the same results as "tightly controlled research studies in which the training is implemented by experienced researchers" (Holmes & Gathercole, 2014, p.441). A class of 8- to 9-year-old students seems to have significantly increased their working memory in the tasks they had trained to do and other tasks. The latter is evidence that tends towards these activities having near transfer effects. The 9 to11 year-old students appear to have showed improvements in the WM tasks. The evidence also indicates that these students achieved significantly greater progress in Maths and English (Holmes & Gathercole, 2014). Although there appear to be significant gains in both WM and educational attainment the WM training was done as a standalone activity and not as part of a lesson. There is evidence to support the fact that students completing short-term standalone intervention do not show long term transfer effects on students in other studies (Dehn, 2008). Furthermore, a review of the evidence supported the view that any effects from brain training interventions were limited only to similar activities and hence only near transfer effects (Howard-Jones, 2014). Furthermore, some research suggests that WM training improves WM with no near transfer effects demonstrated (Himi, Stadler, von Bastian, Bühner, & Hilbert, 2022).

However, there is good evidence to show that stress affects WM (EF) negatively (Diamond, 2010). Hence if these and other similar classroom or curricula interventions are making the classroom less stressful and students are happier. Then the students may show improvements in their WM (EF) that authors of studies or administrators or creators of these programmes may claim were down to the structure of the intervention (Diamond, 2011). On the other hand, it could be that WM training may be able to play a significant part in increasing academic performance; if delivered in the classroom:

"Perhaps if the training tasks themselves became part of lessons, or the tasks themselves reflected more meaningful (*subject related)* tasks, then the effect of training would improve...To this end the objective should not be to train something to have an effect in the classroom, but to change conditions in the classroom so that the training is not needed. Indeed, it may be strategically planning lessons, or starters that have short bursts of intense WM load may be a way of moving forward to our mutual benefit. Further pedagocial research needs to be developed to move WM training away from the computer and into the classroom" (Cunningham & Sood, 2016, p. 12).

The theory and findings from this part of the literature does not conclusively demonstrate the improvement of WM from these interventions or programmes quatitatively. The studies did predominantly rely on quantitative data. This approach was not able to look holistically at the impact of the WM training on the students. This made me reflect on the approach to my study. Although a quantitative approach would be easier to conduct and analyse.

The purpose of my study was to tackle students' underachievement in Science. I wanted to find out what was happening to the students metacognitively, and what impact the activities to develop WM would have on their perception of memory, intelligence and learning science. This meant a pragmatic approach with mixed-methods of data collection. This meant designing student interviews and questionnaires to be able to find out the impact of the the activities to develop WM on many different levels. This in turn also shaped the research questions d. and e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory and learning in Science compared to the control conditions? What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

There is also no research conducted into investigating if WM training may improve student WM and KS3 Science attainment and hence decrease student underachievement in Science. This leads to the broad research question:

What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students? Which can be separated into five distinct questions.

a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, science and learning in Science compared to the control conditions?

e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

2.10 The Issue: Science underachievement being addressed by consistent use of activities to develop working memory as an integral part of KS3 Science lesson plans.

2.10.1 Introduction

The literature for this Section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature.

Table 37 (Appendix A) Shows the literature, how it was selected and a summary of how it was useful to inform the literature review of underachievement in Science using activities to develop working memory as an integral part of the KS3 Science lessons.

2.10.2 Science underachievement being addressed by consistent use of activities to develop working memory as an integral part of KS3 Science lesson plans.

The Baddeley and Hitch model of WM (section 2.4) states that new information goes through the WM in order to be stored in the LTM (Baddeley, 2014; Baddeley & Hitch, 1974). The classroom is a place where students are expected to learn by gaining new information and skills. In order for students to be able to learn and hence use the new information and new skills they must be committed to the long-term memory (LTM). Dehn states: "The pervasive influence of working memory on so many cognitive functions – can mean only one thing – working memory is the lynch-pin of cognitive processing" (Dehn, 2008, p. 63). I believe that WM is important for learning; this is supported in the literature (2. 6 of literature review) and (e.g., Hassed & Chambers, 2014; Miyake, et al., 2000). The heavy demands that are put on WM in the classroom are so great that even students with an average WM can have their WM overloaded with processing of information that also needs to be held on whilst simultaneously listening to other instructions (Petty, 2009).

The current models of WM have only been around since the mid-1970s and hence do not always come at the forefront of pedagogical teaching on ITE programmes or are lost in the many demands and pedagogy of an intensive ITE course (Willingham, 2018).

Therefore, WM is not always taken into consideration when educational practitioners are planning: programmes of study, schemes of work or lessons. This plays a part in the gap that has been identified in the literature. On the other hand, it is also worth emphasising that some ITE courses explicitly include WM, or implicitly via cognitive load. Furthermore, teachers with different A-levels will have varying knowledge of WM. For example, A-level PE and Psychology both include content in their specifications about WM and its' interaction with LTM. Whether teachers who possess these qualifications then use this information to support the planning and differentiation of their lessons is unknown. It is also not known as to what extent teachers who have prior knowledge of WM explicitly link that knowledge to how students learn in their own classrooms. WM is not part of the explicit lesson planning part of the Teaching Standards; nor is it an explicit part of the differentiation part of the Teaching Standards (Unknown, Gov.uk, 2011).

This literature review has demonstrated how there is a gap in the research published both nationally and internationally. Insofar as this researcher is aware; there has to date been no research published on activities to develop working memory created for KS3 Science lessons (Figure 3); whose intention is to develop (train) students' WM and hence increase student Science attainment. There is however support in the literature for teachers developing student WM as part of their lesson plan to increase attainment whilst delivering other subjects (see section 2.9 of the literature review) but not Science (e.g., Cunningham & Sood, 2016; Holmes & Gathercole, 2014; Rode, et al., 2014). An alternative view to the training of WM is to maximise learning whereby teachers use better educational resources to reduce the WM load within their lessons (Cowan, 2014).

The findings and theory from the literature review have demonstrated how the research questions have been developed and how the approach to the study has been shaped. The next section focuses on the theoretic framework of the study.

2.11 How the literature informed my theoretic framework for the research study design (how my research questions will be answered)

2.11.1 Introduction

The literature for this section was sourced using a systematic search of the literature (see Figures 1-3) and a scattergun approach using sources that were referenced in papers that were found in the systematic search of the literature. Table 36 (Appendix A) shows the literature, how it was selected and a summary of how it was useful to inform the literature review that shaped my theoretical framework for the research study. This in turn will be used to justify how the theoretical framework for the research study is appropriate to answer the research questions.

This part of the literature review will outline the theoretical framework for the naturalistic experimental research study design and the literature that supports this design. In particular, explicitly showing where the literature can justify the theoretical assumptions I have made, that led to the construction of the research questions. As well as the justification for the assumptions which led to the gathering of perception and qualitative data that measures aspects of WM and Science learning, metacognition and attainment that cannot be measured quantitatively.

2.11.2 Theoretical Framework for the Naturalistic Experimental Research Study Design

Figure 12 A diagram of the theoretical framework for the Naturalistic Experimental Research Study Design for this thesis

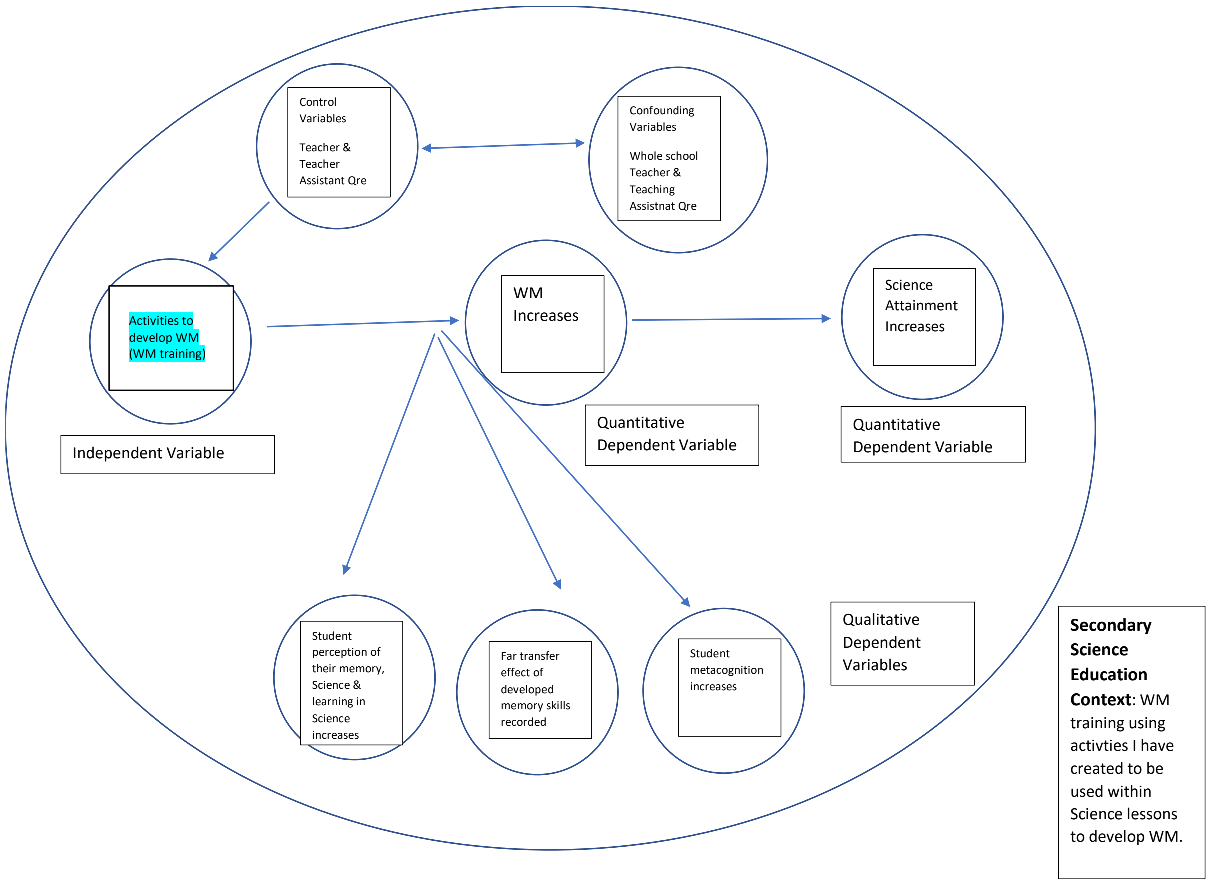


Figure 12 is a diagram to represent the theoretical framework of the naturalistic experimental design that is used in this research study. This theoretical framework enables me to research the different possible layers of impact that the activities to develop WM that I have designed. Impact that is both quantitative and qualitative. The research questions are stated at the end of section 2.9. The key construct of underachievement in Science is tackled using the framework and as the aim of the outcome in Figure 12 & 13. The key construct of underachievement in secondary Science is also with the context of the theoretical framework being embedded in a Secondary Science context. The key constructs of WM and WM is necessary for learning to take place is shown with the Baddeley and Hitch model place within the framework and the quantitative outcomes (Figure 13). The following key constructs are demonstrated in the theoretical framework; WM can be developed (has neuroplasticity), is shown by the outcomes in Figure 12 and 13, people who complete specific activities can increase their WM & completing specific activities in the classroom can increase WM is shown by the presence of activities to develop WM, furthermore the increase in (Science) attainment can be seen in the outcomes to RQ b. (Figure 13)

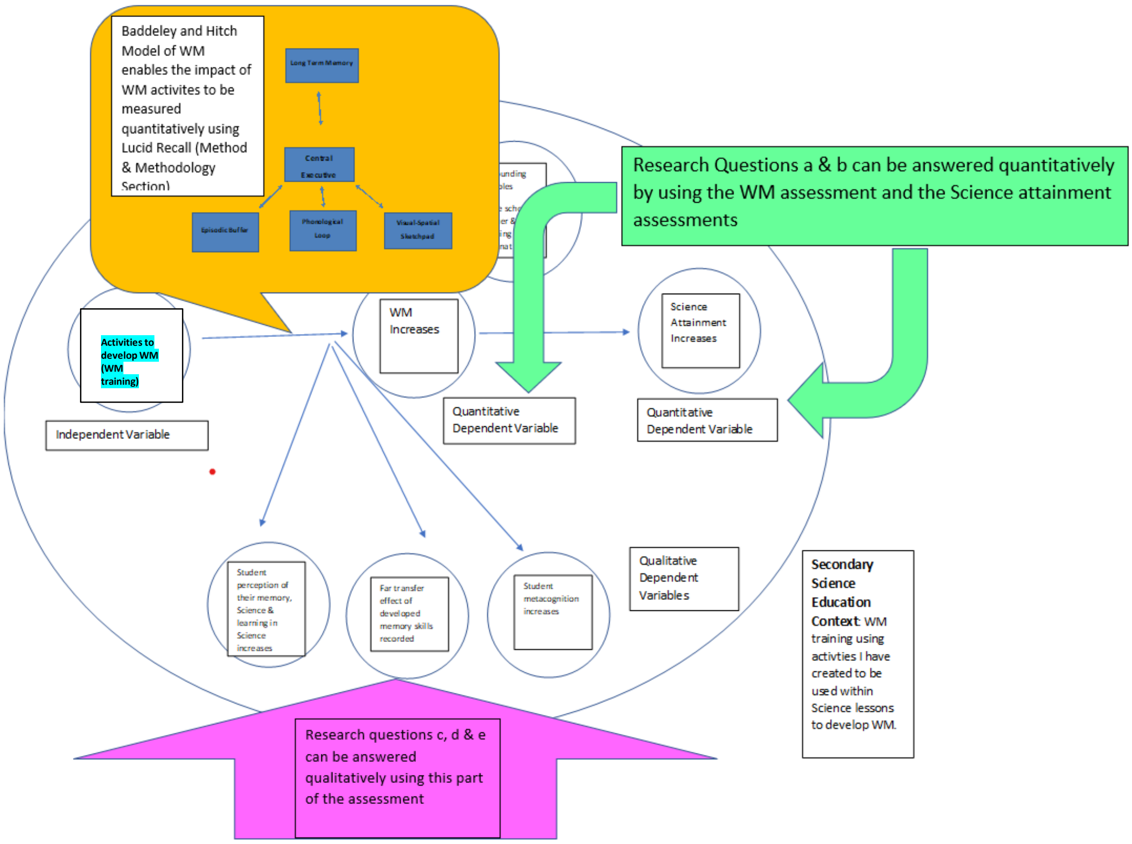
Figure 12 & 13 outline the independent variables, the dependent variables (and where each will answer the individual research questions), the control variables and some of the key confounding variables. This is all set within the Secondary Science Education context. Questions a and b can be answered quantitatively and an experimental design laboratory-controlled experiment would have sufficed. However, as a full-time teacher I am interested in investigating the efficacy of new teaching strategies in a real-life context with the ability to investigate the qualitative changes that may occur to students' perception of memory, science learning, metacognition and far transfer effects. The theoretical framework enables questions c, d, and e also. These differing layers of the research give a depth and richness to the study that will give teachers a more holistic view of the any impact the activities to develop WM have on KS3 students.

Figure 13 outlines how the theoretical framework for the naturalistic experimental design study proposes to answer the research questions. In addition to which, Figure 13 also demonstrates how the Baddeley and Hitch (Baddeley & Hitch, 1974) model of WM fits into the context of the theoretical framework. The key concepts of WM and WM being necessary for learning to take place underpinning the theoretical framework. The Lucid Recall WM assessment (St. Clair-Thompson, 2015) was developed with a researcher who uses the Baddeley and Hitch model to research WM and learning in school aged students (St Clair-Thompson, et al., 2010). Other researchers of WM and learning in school aged students also use the Baddeley and Hitch model as a framework for their WM research (e.g., Ackerman, et al., 2005; Alloway & Gathercole, 2009; Diamond & Ling, 2016;

Gathercole, et al., 2004; Holmes, et al., 2009; Holmes & Gathercole, 2014; Melby-Lervag, & Hulme, 2015;Redick, et al.,).

Figure 13 shows how questions a & b can be answered quantitatively, whereas questions c, d and e can be answered qualitatively within a Secondary Science context. Research questions a & b are supported by the research studies included in sections 2.8, 2.9 and 2.10 of this literature review demonstrate that previous studies have evidence to support WM training using the Baddeley and Hitch Model within their design framework to improve attainment in school aged students (e.g., Holmes, et al., 2009; St Clair-Thompson). This training can be seen in the theoretical framework design (Figures 12 & 13) as the activities designed to develop WM. This envelopes two of the key constructs of this study; WM has neuroplasticiy and people who complete specific activities increase their WM. Hence, the next part of this section will mainly focus on the justification of assumptions made for research questions c, d and e; where there is a heavier reliance on perception and qualitative data. Although the perception and qualitative data will contribute in a small way by considering different strata of answering research questions a and b so this is also considered.

Figure 13 How the theoretical frame work of the naturalistic experimental design for this research study proposes to answer the research questions and where the Baddeley and Hitch model of WM fits into the



2.11.3 The justification within the literature for the theoretical assumptions made for formulating the research questions for collecting data on changes inWM and changes in students' LTM and learning

Table 1 outlines the theoretical assumptions made when formulating the research questions (these are referred to in the methodology section of the thesis disseration Chapter 3). Assumptions 1 and 3 are supported by extensive literature that is reviewed in section 2.4 of this chapter. The literature reviewed in section 2.4 clearly link the WM with the LTM. Suggested changes within the LTM have been demonstrated in a number of studies (see Sections 2.8, 2.9 and 2.10 of this literature review)with attainment improving in for example maths and reading (Carretti, et al., 2014; Holmes, et al., 2009; St Clair-Thompson, et al., 2010; Van der Molen, et al., 2010; Westerburg & Klinberg, 2007). This links the two key constructs of this study; WM is necessary for learning and increasing WM increases attainment.

Table 1 The literature to support the theoretical assumptions made in the theoretical design frame work for this thesis.

Theoretical assumptions made on formulation & construction of the research questions with support from the literature	The research questions impacted by the assumption	Literature to support the assumption
1. Learning being a change in the LTM caused by changes to (or efficiency of) the students' WM	b	Section 2.4.3 of this literature review justifies the use of the Baddeley and Hitch Model of WM (Baddeley & Hitch, 1974)in an education setting as the model links learning to new information entering the LTM via the WM Westerburg, H., & Klinberg, T. (2007). Changes in cortical activity after training of working memory - a single-subject analysis. *Physiology and Behavior, 92*, 186-192. Sections 2.8, 2.9 & 2.10 of this literature review discuss WM training in students & how this has an impact on learning. Examples of studies that are in line with the Baddeley and Hitch model of WM & changes in LTM are: Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*(4), F9-F15. St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. *Educational Psychology, 30*(2), 203–219 Van der Molen, M. J., Van Luit, J. E., Van der Molen, M. W., Klugkist, I., & Jongmans, M. (2010). Effectiveness of a computerised working memory in adolescents with mild to borderline intellectual disabilities. *Journal of Intellectual Disability Research, 54*(5), 433-447.

		Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training. *British Journal of Educational Psychology, 84*, 194-210. Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research, 78*, 852-868.
2. Changes in WM can be measured qualitatively using questions in interviews questionnaires	a, c, d	Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge. Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD. Diamond, A. (2011). Activities and Programs that improve Children's Executive Functions. *Current Directions in Psychological Science, 21*(5), 335-341. Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research, 78*, 852-868. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.
3. Any changes to the LTM within a Science lesson are directly linked to the WM based on the Baddeley and Hitch Model (Figure 4 and Figure 10)	a, b, c, d	Section 2.4.3 of this literature review justifies the use of the Baddeley and Hitch Model of WM (Baddeley & Hitch, 1974)in an education setting as the model links learning to new information entering the LTM via the WM.
4. The changes to WM and LTM will be noticeable explicitly to the students	a, b, c, d, e	Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge. Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD.

		Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research, 78*, 852-868. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.
5. Students would have the ability to recognise that their memory and intelligence may be changing	d, e	Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264. Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge. Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.
6. Students can recognise if they are learning more information	b, d, e	Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264. Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge.

		Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.
7. Students know when they are finding it harder or easier to learn	c, d, e	Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264. Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge. Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.
8. Students are able to understand and able to state orally which activities have helped them learn the most	b, c, d, e	Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264. Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge.

		Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD. Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. *British Journal of Educational Psychology, 84*, 194-210. Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.

Assumptions 2, 4-8 are based on studies that have evidence to support that students are able to recognise and reflect upon changes to their WM and its' impact on their learning. The 2014 Carretti et al study and the Carnoldi et al 2015 study include the use of questionnaires and gather data on student metacognition both reporting positive results in regards WM training and attainment (Carretti, et al., 2014; Cornoldi, et al. 2015). However, there are relatively few published studies that included training WM and used qualitative data. The 2008 meta analysis of self regulation by Dignath & Gerhard, B. provides more evidence that helped me formulate and support the assumptions that 5 – 8; demonstrating that there are studies successfully using qualitative data to investigate if students are learning more and how different strategies impact their learning. As learning within this thesis uses the Baddeley and Hitch WM model (Baddeley & Hitch, 1974) then students reflecting on their learning positively is linked to an increase in size or efficiency of the WM.

This is further supported by literature published in books; Hattie has supporting evidence of metacognition in the classroom where students can orally and via the use of questionnaires state if they are learning (Hattie, 2009, pp. 188, 217)and Petty (Petty, 2009). There is no literature as far as I am aware specifically on students reflecting on their intelligence or memory. However, Dignath also published a meta-analysis in the context of self regulated learning that demonstrates that there are studies that have reported on students' metacognition using a range of data collection techniques that did not exclude mixed methods studies (Dignath & Gerhard, 2008). Hence there is literature that supports assumptions 2, 4-8; although there are not a great many. This can be attributed to the vast majority of education research studies being tightly controlled, usually short term (weeks not years) with relatively small sample sizes (in the 10s not 100s); these types of studies tend towards quatitative data where a clearer impact can potentially be demonstrated in a smaller time scale.

This demonstrates that I have reflected on the naturalistic experimental design using a mixed methods approach to data collection to answer my research questions. The assumptions I have made in order to collect the data have been discussed and supported with theory and findings from the literature. In turn these have also been linked to the seven key constructs; 1) underachievement in secondary science, 2) WM (definition of WM), 3) WM is necessary for learning to take place, 4) WM can be developed (has neuroplasticity), 5) people who complete specific activities can increase their WM, 6) increasing WM increases (Science) attainment and 7) completing specific activities in the classroom can increase WM and hence increase (Science) attainment. The theoretical framework (Figure 13) designed to answer my research questions is supported by the theory and findings of the literature .

Chapter Three Methods and Methodology

3.1 Design

3.1.1 Justification of a Pragmatic Paradigm

I have identified, understand, and justified in the literature review the contrasting world views that frame education research; and have used these to consider the differing stand points on what is and how knowledge is gained when researching WM, learning and Science attainment. In recognition of those ontological and epistemological stances; opposing approaches to the research have been considered. This identification, understanding and consideration has led to me developing a post-positive approach to the research using a pragmatic paradigm.

As I have justified in the literature review; I will be using a pragmatic paradigm to approach the research into WM, learning and Science attainment. The pragmatic paradigm will allow for the research questions to be at the centre of the research (Duemer & Zebidi, 2009). As opposed to the realist philosophy driving the approach (Carr, 2010). This pragmatic paradigm enables me to combine quantitative and qualitative data collection (Mackenzie & Knipe, 2006). In order to establish if there are measurable links between WM, learning and Science attainment. WM can be tested and quantified; in the same manner assessments of learning can be used to quantify Science attainment during the research. Furthermore, the mixed methods approach and analysis of the data will be able to utilise qualitative data to enrich and validate the conclusions drawn from the quantitative data analysis (Salehi & Golafshani, 2010). This will enable the me to look for both measurable cognitive effects but also qualitative metacognitive effects and non-cognitive impact of WM on learning and Science attainment and vice versa (Johnson & Onwuegbuzie, 2004).

The choice of a pragmatic paradigm can be justified by looking at the choice of the research and my stance as a full-time classroom teacher. This means that I am concerned with the practical issues in a combination with reading and studying the academic research literature; focusing my attention on improving KS3 students' Science attainment rather than focusing on philosophical viewpoints or debates (Weaver, 2018). The practical issues dominate my focus as having a real-life impact on the students I work with is the driving force behind my research. Having my research embedded within a pragmatic paradigm enables me to take action with my research; the outcomes of which may well advance the life chances and hence long term enrich the life of KS3 students. Therefore, making a difference to a group in society with an emphasis on finding the knowledge that will help the KS3 students rather than an absolute truth (Weaver, 2018). The pragmatic paradigm allows me as both a researcher and teacher to take the knowledge I started out with; about developing WM and the impact increasing WM may have on the science attainment of students at KS3 and continually review that knowledge and either keep, discard, or modify the knowledge (Feilzer, 2010). This is the research process that I believe best serves the interests of the KS3 students whose lives I would like to positively impact on with the outcomes of this research.

The research previously undertaken by myself; I am a full-time teacher has consistently had student welfare and attainment at it's heart and hence has been very much classroom centred. The antecendent for this thesis has come from an aim to overcome underachievement in students. This it is believed can be done by considering how students respond to activities in the classroom. Evidence Based Teaching as cited in *A Visible Learning: A synthesis of over 800 meta-analysis relating to achievement*, 2009 (Hattie, 2009) and *Evidence Based Teaching*, 2009 (Petty, 2009) for me has the potential to have the biggest impact on student learning.

3.1.2 Justification of this research study using the Baddeley and Hitch Model of WM in the context of ontolology, epistemology, research design framework and my own theoretical assumptions

The Baddeley and Hitch Model of WM (Baddeley & Hitch, 1974) is a key component of this research study (see Chapter 2 section 2.4.4). The entire research study is based on the questions that centre around whether a set of activities I have created to develop WM have any impact on the active group compared to the control group conditions. The change in WM that may be evidenced from the data collection and analysis will be assumed to be a change to the size (or efficiency) of the constructs (and their interactions with one another). Hence, it is important to justify and explain the ontology, epistemology, and research design framework in the context of the Baddeley and Hitch WM model. I have put this information in Table 2 shown below.

Table 2 A justification of this research study for using the Baddeley and Hitch Model of WM in the context of the ontology, epistemology, and the research design frame work

Research World View	World View Justified for this research study	Justification of using the Baddeley& Hitch Model of WM
Ontology	Pragmatic Paradigm	Whether or not WM can be developed using activities I have created to be used in KS3 Science lessons is at the centre of the research. A pragmatic paradigm enables me to have the research question at the centre of my research. The Baddeley and Hitch Model can be linked to how students learn in a KS3 classroom (Section 2.4, 2.5-2.10 of the Literature Review) and is measurable using the Lucid Recall Test (see quantitative data justification later in this chapter). This

		enables quantitative data to be collated on student WM.
Epistemology	Neither: I view knowledge from both a realism and constructivism standpoint. This enables me to look at the impact of WM activities I have created to develop WM on many different levels	Epistemology within a pragmatic paradigm, accepts that knowledge will change over time and to be able to accept this changing knowledge as evidence occurs to change our understanding of a concept. The Baddeley and Hitch model of WM has changed over time with the original model being a tripartite model with 2 slave systems (Figure 4) and as rehearsing (Cowan, et al., 2005) and capacity (Baddeley, 2001) evidence came to light the Baddeley and Hitch model of WM changed to a three-slave system (Figure 4 Section 2.4) Furthermore, this model is simple enough with its non-overlapping constructs to be shared with KS3 students (in a differentiated manner) to support their understanding of

		how the WM activities may be helping their memory and support student metacognition. This supports the gathering of the perception and qualitative data.
Design Framework	Naturalistic-Experimental Design: This fits well within a pragmatic paradigm and the epistemological stance. As it enables me to analyse the multileveled impact of the WM activities, I have created to develop WM in a real-world context not a laboratory. Leading to being able to see the impact of my research in the real world on the social issue of underachievement (the socio-economic gap)	The Baddeley and Hitch model of WM (see chapter two, section 2.4 Figure 4) has no constructs overlapping with other areas of memory which makes quantitative data collected to measure WM more valid and reliable. Furthermore, the use of the Baddeley and Hitch model as a way of explaining how learning occurs supports the gathering of perception and qualitative data. This model is simple enough with its non-overlapping constructs to be shared with KS3 students (in a differentiated manner) to support their understanding of how the WM activities may be helping their memory and support student metacognition. This supports the

		gathering of the perception and qualitative data.
Theoretical Assumptions	The students are all able to access the tests and assessments used to gather WM and Science attainment data. So, the data will be comparable. The Science teachers in the active group will generally deliver the WM activities I have created to develop WM in their lessons with minimal variation of delivery between teachers. The Science teachers in the control group will generally deliver "normal way of teaching" lessons with minima variation of delivery between teachers. The students will interpret the questions I ask them in the student interviews in a similar way	The Baddeley and Hitch model of WM (Section 2.4 Figure 4) has no constructs overlapping with other areas of memory which makes quantitative data collected to measure WM more valid and reliable. The Baddeley and Hitch model of WM (Section 2.4 Figure 4) has no constructs overlapping with other

	The students will interpret the questions being asked in the student questionnaire in a similar way The myriad of other confounding variables that I am unable to measure for students in and out of school will have a similar impact on each student's WM.	areas of memory which makes qualitative data collected that relates to LTM can be linked back to the WM. Furthermore, the use of the Baddeley and Hitch model as a way of explaining how learning occurs supports the gathering of perception and qualitative data. This model is simple enough with its non-overlapping constructs to be shared with KS3 students (in a differentiated manner) to support their understanding of how the WM activities may be helping their memory and support student metacognition. This supports the gathering of the perception and qualitative data.

3.1.3 Justification of a naturalistic experimental design framework

The experiment design frame holds at its' heart the demonstration of cause and effect (Cohen & Manion, 1994). This frame work would enable the research questions (restated below in Table 3) to be answered. The different methods of data collection and how they will explicitly answer the research questions are stated in Table 3 with further detail about data collection methods in Table 5.

Table 3 The research questions and the data collection and approaches that will be used to explicitly answer each question

Research Question	The data collection devices and approaches that will explicitly answer this question
a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?	Quantitative data: Using the software package Lucid Recall (St. Clair-Thompson, 2015)to measure the students' WM pre and post exposing the active group to the activities to develop WM and exposing the control group to the "normal way" of teaching Year 7 and Year 8 students.
b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?	Quantitative data: Students' attainment scores from school in house Science assessments. • Science Tests (Year 7 and 8) • Science Investigative Skills (Planning, Obtaining Evidence, Analysis, Evaluation) (Year 7 and 8) • End of Year Grade (Year 7 and 8) • Science Homework Grades (Year 7)
c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?	Perception Data: The students' responses to the student interview questions and student questionnaire questions gave a quantitative measure of any far transfer effect being experienced by the active group students.

	Qualitative Data: The students' responses to the open student interview questions were analysed using the constant comparative method to identify general themes in the responses. The students' responses where appropriate as quotes or similar verbal/written responses were reported in the analysis to demonstrate far transfer effects.
d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, science and learning in Science compared to the control conditions?	Perception Data: The students' responses to the student interview questions and student questionnaire questions gave a quantitative measure of any difference in students' perception of memory, science and learning in Science within the active group or control groups. Qualitative Data: The students' responses to the open student interview questions were analysed using the constant comparative to identify general themes in the responses. The students' responses where appropriate as quotes (or paraphrasing of their opinions) oral/written responses.

	The constant comparative method and direct responses from the students were used to look for evidence of any difference in students' perception of memory, science and learning in Science within the active group or control groups. (Coding and final analysis are shown in Appendix E) Additional informative quantitative data: The data I collated from lesson observations was a frequency count recording of whether I could see evidence of the WM activities being used in the lesson; in combination with time sampling the part of the lesson I was observing (i.e., start, middle or end) was used. (Coding and final analysis are shown in Appendices D and E)
e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?	Perception Data: The students' responses to the student interview questions and student questionnaire questions gave a quantitative measure of difference in students' metacognition within the active group or control groups. Qualitative Data: The students' responses to the open student interview questions were analysed using the constant

	comparative method to identify general themes in the responses. The students' responses where appropriate as quotes (or paraphrasing of their opinions) were reported in the analysis to demonstrate difference in students' metacognition within the active group or control groups. (Coding and final analysis are shown in Appendices D and E) Additional informative quantitative data: The data I collated from lesson observations was a frequency count recording of whether I could see evidence of the WM activities being used in the lesson; in combination with time sampling the part of the lesson I was observing (i.e., start, middle or end) was used.

I have chosen to embed my research within a pragmatic paradigm as this means that I can at the same time take on the viewpoints of the realism and constructivism. This has given me the time and energy to pay attention to the research questions and pursuing the knowledge about developing WM and hence Science attainment in KS3 students. A pragmatic paradigm allows for me to see reality as different strata. These differing levels of reality may be investigated and examined using a diverse range of data collection devices and approaches (Table 3). This mixed methods approach includes collecting qualitative and quantitative data.

I am a full-time classroom teacher so I wanted my research to have a real-world application to the knowledge being gained and discounted. So that I could make a difference to the KS3 students Science attainment and hence, ultimately their life choices. This has led me to have a naturalistic-experimental research design approach rather than laboratory research. This research design within a pragmatic paradigm has led to be able to have a “multilevel sequential mixed design” (Teddlie & Tashakkori, 2009).

Isolating lessons where activities to develop working memory are included within KS3 Science lessons, the students are exposed to in science and measuring WM and Science attainment. Whilst taking into account (in some way measuring) the myriad of variables in an education setting of secondary school and the social setting that will impact on students WM and Science attainment. Similarly, another challenge that will need to be considered and taken into account is that the variables that have been isolated (WM, Science attainment) change over time. WM increases with age (Alloway, 2009) and any type of teaching and learning strategy will make a positive difference to student attainment (Hattie, 2009).

The research to answer the research questions about WM, learning and Science attainment took place over two years. In addition, the research followed a cohort of students over a significant period of time and utilise existing data sets of science attainment on those students over that time. But did not use a longitudinal design frame but an experiment design frame due to the isolation and manipulation variables by myself. The experiment design frame is often held up as the gold standard of all design frames and there have been calls for more experiment designs using randomised controlled trials in education research (Torgerson & Torgerson, 2008). However, many researchers have refuted this arguing that the dynamic shifting nature of the confounding variables make the experimental design unrealistic in a classroom setting (e.g., Cartwright, 2007; Hammersley, 2015; Kounin, 1970; MacIntyre, 1985). The important factor in choosing a design frame is that it facilitates me to answer my research questions. The naturalistic experiment design frame with the rigor of its’ procedures and rules enabled me to obtain reliable data on WM and Science attainment, to draw valid conclusions, with ultimately some degree of external validity. But the naturalistic aspect will take into account the fact the research is taking place within the classroom and not in controlled laboratory conditions.

I have considered the possible design frames and justified the choice of the experiment design frame. However, this will be conducted using a mixed methods approach to data gathering within an experiment design frame (Gorard with Taylor, 2004). Hence, I do not hold with the opinion that mixed methods research is a design frame but a way of gathering data within the naturalistic experimental design frame. I will gather quantitative data on WM and science attainment. The intention is for the qualitative data to illuminate and provide a greater understanding of any observable changes in the WM tests and hence Science attainment quantitative data. In addition, the qualitative data will enable triangulation on any possible cognitive and non-cognitive outcomes of the research study.

3.1.4 Theoretical Assumptions (embedded within the Ontological, epistemological, and naturalistic experimental design framework)

There are a number of theoretical assumptions that I have about Working Memory and Science attainment that led to a mixed methods approach to data gathering. The pragmatic paradigm allows me as a researcher to have the question of WM and how it impacts on KS3 Science attainment at the centre of the research. The epistemology embedded within the pragmatic paradigm enables me to gain and discard knowledge to best understand how WM training may impact KS3 Science attainment in students. This facilitates the naturalistic-experimental design framework that means that the impact of activities I have created to develop WM in KS3 Science lessons can be investigated on a number of different levels. This leads to gathering both quantitative and qualitative data. The theoretical assumptions I have about WM and Science attainment included gathering data about students' views and perspectives in interviews and Student questionnaires (these are looked at in more detail later on in this chapter – Tables 5 & 6).

However, these theoretical assumptions include the fact that changes in WM can be measured both quantitatively using Lucid Recall that was designed based on the Baddeley and Hitch Model of WM (Carretti, et al., 2014; Holmes, et al., 2009; St Clair-Thompson, et al., 2010; Van der

Molen, et al., 2010; Westerburg & Klinberg, 2007) and qualitatively using interviews and questionnaires (Carretti, et al., 2014; Cornoldi, et al., 2015; Dignath, C., & Gerhard, B, 2008; Hattie, 2009). I have assumed that any changes to the LTM within a Science lesson are directly linked to the WM based on the Baddeley and Hitch Model (Figure 4). I have assumed that changes to the LTM made in student's brains will be measurable using Science attainment assessments. I have assumed that some of the changes to WM and LTM will be noticeable explicitly to the students. The questions I have designed for the student interviews and student questionnaires are directly linked to these assumptions and are justified in more detail in Tables 5 and 6). These explicit changes I have assumed would be to their ability to recognise that their memory and intelligence may be changing, that they are learning more information, that they are finding it harder or easier to learn, and that they are able to state which activities have helped them learn the most. These theoretical assumptions are based on this learning being a change in the LTM caused by changes to (or efficiency of) the students' WM. In summary, the theoretical assumptions I have made in relation to WM and Science attainment have led to the decision to use a mixed methods approach.

I intend to collect some of the qualitative data myself; specifically, lesson observation and student interviews. Although I fully intend to be an objective observer and interviewer. I will establish their positionality within the research. This chapter will outline my values, beliefs and philosophy and will help contextualise the lesson observation and student interview qualitative data. This will also illuminate the antecedents of my expectancy effects.

I am female, in my mid-forties and of white British ethnicity. I work full time as a Science teacher and hold the the post of KS3 Science Co-ordinator in the school, am a lone parent of two children and from a working class background. I was the first in my family to obtain an Undergraduate degree and a Masters degree. The values, beliefs and philosophy I hold have been held implicit within me, are built into my personality and define who I am as a person. Although, I have been teaching for a long time; they have held these deeply values and beliefs that were held well before I trained as a teacher in my mid-twenties.

However, I do not believe that a student's attitude to learning or ability to learn are set in stone and with the correct mindset, place and people around a person there are no limits. Teachers and the way they deliver content and activities within a lesson are pivotal for the cognitive development and education of children. Conversely if a teacher is not an effective practitioner, or the students do not have a supportive home background this has shown to have a negative effect on students attainment (Macleod, et al., 2015). Furthermore, teaching students values such as respect, tolerance, kindness and meditation are positive. This has been shown to have a good impact on students. The absence of these from the school curriculum and or ethos can have a negative impact (Weare, 2012; White, et al., 2017). However, for me it is Evidence Based Teaching (as cited in Hattie, 2009; Petty, 2009) that has has the potential to have the biggest impact on student attainment. Research should have a big impact on how students learn in the classroom and a clear aim to increase students' life chances and hence choices.

3.1.5 Summary ontology, epistemology and research design framework adopted for this research study

In summary, this study adopts a pragmatic paradigm, embedded within this is an epistemology that does not hold with either constructivism or realism but instead allows knowledge to be gained and discarded in order to focus on the research question and any positive ways this may impact on the Science attainment of KS3 students (Table 5 to see how each data collection approach is used to answer each of the research questions). This study has the research questions at its heart and how the outcomes may positively impact on the attainment of KS3 students and ultimately support the closing of the SES gap. In light of this, the research is being conducted as a naturalistic-experimental design. This enables me to ensure that the activities I have created to develop WM are tested within a real education environment and not a laboratory. Although this brings its own complexities in taking into account the myriad of confounding variables. This design framework also enables me to investigate the many levels of impact the activities I have created to develop WM may have on students (Table 5 shows how each data collection approach is used to answer the many levels of impact covered by each of the research questions). This design framework and my theoretical assumptions means I am gathering quantitative and qualitative data to answer the research questions.

3.2 Participants

The school where the research took place was a rural fully comprehensive secondary school in East Devon; for students of 11 to 18 years. The school was chosen as I work there full-time as a Science teacher and also hold the post of KS3 Science co-ordinator. Hence, gaining access to the school and obtaining permission from the Headteacher to conduct the research at the school was less of a challenge than if I had been trying to gain access to the school from an external standpoint. I am as a full-time member of staff was able to gain access to participants and staff in order to gather the data needed to conduct the research.

I had a number of local schools in the West Country who had registered an interest in being involved with the research. However, on reflection there were a number of insurmountable challenges to conducting the research in another school. The West Country is a large mostly rural area so travelling between home, work and another school would have been time consuming. My employer was not able to grant paid leave for the time needed to conduct the research. I could not afford to take unpaid leave to conduct the research. Furthermore, I would not have had an in depth understanding of the ethos, day to day running and systems of another school.

The participants of the research are an entire year seven cohort of 182 students (six students left during the year and were replaced as an oversubscribed school with new students that were excluded from the study). None of the parents opted their child out, however 5 students chose not to opt themselves in and were excluded from the WM testing, questionnaire, and interview part of the trial. Their data was included in the Science attainment data as per the ethics forms and permission. The entire cohort were chosen with the aim of obtaining a large data set that would enable valid conclusions to be drawn, with ultimately some degree of external validity (See Table 5).

The research questions' specific focus is on KS3 students' Science attainment. The Year seven cohort were chosen for the research study because the year group could be studied for two years of their KS3 Science education. I considered, having a cohort of two-year groups; year seven and year eight (approximately 360 students) concurrently over two years. However, being a researcher that worked within the research school presented a challenge to doing the research with two-year groups at the same time.

I wanted to avoid experimenter effects such as the Hawthorne effect and to reduce to a minimum any expectancy effects (Cohen & Manion, 1994). To achieve this, I would have to be excluded from Year seven and Year eight Science teaching. This was not possible due to timetabling constraints. I could be excluded from teaching either year seven or year eight science but not both year groups. In the school where the research took place the Year nine curriculum (and to some extent lesson structure) shifts to GCSE half way through the academic year. This also ruled out using Year 8 students over two years. The Year nine cohort were not chosen for a number of reasons; curriculum changes during the Year nine academic year, I would not be able to follow them for two years of their KS3 education and usually Year nine teaching time at the research school are split between two teachers increasing the variability of one of the confounding variables in the study.

The Year seven cohort of students are placed into six classes (these are predominantly allocated in late June (with some small changes in July) before they start in September allowing for a smooth transition from Primary to Secondary School). The students are allocated into these six classes based on a number of factors. The then, Year six students name three friends that they would like to be in a teaching group with. These students can be from their own or any of the other feeder primary schools (the research school has five main feeder primary schools and can take students from over 10 different primaries each year). The teacher who allocates the students to their teaching group used the student's choice of friends (they have at least one friend in their teaching class with them), maintained a gender balance that was representative of the year group as a whole, used all available assessment data to ensure each class had a mixed ability range that is representative of the year group (including distribution of students with an Education Health Care Plan (EHCP)); whilst not putting too many students from the same feeder primary school in the same class. This process was further informed by information from the primary schools, requests from parents and the observations of staff during the Year six induction week students' experience at the research school during July 2018.

Hence, I had no influence on which students were placed in which class. The class allocation is done to ensure the mental well-being of the Year seven students and to create an environment conducive to learning with the correct mix of students. As part of the school's ethos all classes in all year groups within the school are taught as mixed ability classes (except for maths where students are setted in Years seven to eleven).

This is a quasi-experiment design, and not a true randomised controlled trial. This is because the students have not been randomly placed into two groups. Nor have the two matched groups been randomly allocated to the active or control conditions. However, the six teaching groups were comparable (with overlapping standard deviations) in terms of ability as measured by CAT4 Fourth Edition (Digital) Cognitive Abilities Test (Lohman & Smith, 2014) and age. The active and control groups have a similar but more variable gender divide. Hence, I allocated each of the six predetermined classes (and hence also their teachers) randomly into either the active and control group.

Table 4: The active and control group CAT scores, age, and gender split.

	Active group			Control group	
Class	CAT Score Min/Max (Mean)±SD	Gender F:M	Class	CAT Score Min/Max (Mean)±SD	Gender F:M
A	83/124(106.56)±11.76	16:14	D	79/127(102.24)±10.56	15:16
B	80/122(102.83)±9.73	14:16	E	87/126(106.65)±9.59	15:16

C	78/129(106.96)±12.03	14:17	F	78/124(107.81)±10.00	12:19
Overall	78/129(105.39)±11.29	44:47	Overall	78/127(105.55)±10.57	42:49

The teaching participants, are the seven (one teacher went on and one came back from maternity leave) Science teaching staff from the first year and eight (three classes had two teachers) teaching staff from the second year of the research. There were three teaching assistant participants in the first year and five in the second year of the research. In the first year of the research there were 139 staff in total working at the research school (exclusive of canteen staff and cleaning staff that did not have sufficient contact with students to justify asking them to respond to a questionnaire) 72 of which were teaching staff and 67 were support staff that were asked to respond to a questionnaire. In the second year there were 130 staff of which 70 of which were teaching staff and 60 were support staff; that were asked to respond to a questionnaire.

3.3 Data Gathering

3.3.1 Justification of participants within a pragmatic paradigm

I have chosen to embed my research within a pragmatic paradigm. This has shaped the choice of participants, because a pragmatic paradigm is one where I am able to take action and gather knowledge to make a real difference to a group within society. In this research study this is specifically KS3 students. This has led to a naturalistic-experimental design meaning the research took place in a real world setting of a secondary school in rural England rather than in a laboratory.

This means that the knowledge gained is easily transferrable to other schools both nationally and internationally. However, working in a real-world context that the pragmatic paradigm enables also limited how much influence I had over randomising and balancing the students in terms of gender and ability the control and the active groups. Because the research happened in a real-world secondary school the Year 7 classes were put together by one of the lead pastoral team to ensure there was a good mix of students from different feeder schools, as well as gender and ability mix. This led to the 6 teaching groups being put together prior to the start of the research and not by myself for the purposes of the research but for the purposes of positive pastoral and academic outcomes. This is of course absolutely necessary because of real world context the pragmatic paradigm has led me to be working in.

However, I was able to randomly allocate the six different teaching groups to either the control or active group; and to report on their balance of gender and ability (see Table 4). These were very similar with similar sized standard deviations, indicating that the data profile for each aspect was similar too. So, despite the possible drawbacks of randomising participants; the naturalistic-experimental research design embedded within a pragmatic paradigm still enabled me to randomly allocated them to the control or active groups.

3.3.2 Introduction

The experiment design frame with the mixed method approach means that both quantitative data and qualitative data were collected for this research. The combination of the quantitative data and the qualitative data was integral to enabling valid conclusions to be drawn, with some degree of external validity. The different types of data gave a much fuller picture of the impact of the lesson structure of the active group in comparison to the control group. Whilst also being able to provide transparency and triangulation of the data; so, the findings would have more validity and credence.

The research questions aimed to shine a spotlight on the link between WM, learning, and Science attainment; to explore a possible intervention for closing the SES attainment gap. Whilst also drawing attention to the value of teachers conducting research in the classroom. Hence, aiming to bridge the gap between classroom practice and academic education research.

3.3.3 Justification of mixed methods data gathering

There were a wide range of different data gathering tools and techniques available to me. Table 5 shows a summary of the type of data gathered to answer of my research questions. The following chapters will describe, explain, and justify my choice of data gathering tools. As I have mentioned previously in this chapter of the thesis. Embedding my research within a pragmatic paradigm has enable me to take “a multilevel sequential mixed design” (Teddlie & Tashakkori, 2009, p. 151). It was important to me that the varying research methods and approaches informed and enhanced one another. This was particularly important because not only were they focused on diverse strata of this research study, but they are selected from diverse research approaches (namely qualitative data collection, perception data collection and qualitative data collection).

This mixed methods to data gathering will be able to utilise qualitative data to enrich and validate the conclusions drawn from the quantitative data analysis (Salehi & Golafshani, 2010). This enabled the me to look for both measurable WM and Science attainment. Furthermore, I could also gather data on the perceptions of the students and teachers who took part in the study. As well as data on the qualitative metacognitive effects and non-cognitive perceptions of the students and teachers who took part in the trial. Ultimately this gave me a well-rounded and in-depth set of data to answer the research questions about the impact on developing WM on learning and Science attainment and vice versa (Johnson & Onwuegbuzie, 2004).

Table 5 The type of data collected for each research question for this thesis study; alongside the procedure to the collect the data, the method of data analysis the product of the data collection and has an additional row for data collected to support the transparency of the study

Research Question Letter	Type of Data Collection	Explanation of the procedure undertaken to collect the data	Method of data analysis	Product of data collection
a.	Quantitative	Pre and Post Lucid Recall WM Tests: Lucid Recall is a WM test that is undertaken by using the Lucid Recall Software on a computer. The participants were taken a class at a time to the IT suite at the school. A volunteer who was trained in administering the Lucid Recall test talked the class through logging onto the software and how to access the test (including each aspect of the test and checking headphones were working). There was a teaching assistant present to support with this process. The students then completed the test on the computer with the trained adult on hand for student support. The trained adult was also able to monitor the students to ensure all the students completed the test as the designers of the software intended. This ensured that the there was consistency between all the students when undertaking the WM assessment.	Method of data analysis The data from the student's Lucid Recall test results was exported to a MS Excel document as raw data to make the data easier to manipulate and export into IBM SPSS. The data were then analysed using IBM SPSS Statistics Software Independent t-tests were run on the pre-test data between the control and the active group and post-test data (end of Year 7) between the control and the active group to look for differences between the means of the two conditions	Product I conducted descriptive & inferential statistical tests to see differences in my quantitative data – the Lucid Recall WM Test results. The product of the inferential statistics the independent t-tests, enabled the non-significant and significant differences in the means (using the t values and the p-values) between the control group and the active group to be identified(Table 11 & Table 12 p. 195 & 196) .
	Mixed	Student interviews: Student interviews were conducted by me during my PPA time. I had a Science timetable of every class involved in the study during my PPAs. I used this as a schedule to regularly go into the Science lessons to conduct student interviews (I would conduct lesson observations during the same visit – see below). In each year of the study there was one class that were harder to observe as I had no PPAs during their lessons. In that case I asked a colleague to cover for me whilst I conducted the student interviews. This enabled me to interview many students without it having an impact on my full-time teaching commitment at the school. The students were interviewed in the lesson by me either sitting or standing with them and reading the questions from the interview sheet (Appendix G p. 491 and 501) and	Method of data analysis: Using the IBM SPSS Statistics Software, the results of the descriptive statistical analysis of responses in the Control and Active group were organises as sets of quantitative comparative data in frequencies and percentages. This made comparisons between the control and active group easier to make. Qualitative data in the form of responses to open and free response questions were analysed using the constant comparative method to identify general themes. This was done by reading through all the student interview responses and in the first instance writing down all the words that were activities or words linked to memory and learning. The responses were then grouped into common themes or words and the raw data was revisited to record	Product I conducted descriptive statistics to identify differences between the active and control responses. Frequency tables giving qualitative data for the students' responses to questions in the active and control groups that could be compared. The constant comparative method results were placed in tables with frequency of the words identified for both the control group and the active group were formed so comparisons could be made. These frequency tables can be seen in the data analysis chapter Table 22 p. 224 and Table 25 p. 227 (the raw data Tables 57-64, p. 434-440 can be found in Appendix E).

		recording their answers hand written word for word on the interview sheet.	how many times those words were mentioned in student responses. These frequency tables can be seen on p 287 in the data analysis chapter Table 22 p. 224 and Table 25 p. 227 (the raw data Tables 57-62, p. 434-440 can be found in Appendix E). Qualitative quotes and paraphrased student opinions were used also identified and used to answer this research question.	
	Mixed	Student Questionnaires: The student questionnaires were completed in Science lessons. The student questionnaires were printed versions of the questionnaires in Appendix G p. 485 & 495. The students completed each questionnaire at the end of a science lesson during the same week. The students completed the questionnaire at the start of study just after the Lucid Recall Pre-Test was completed and then at the end of the summer term of Year 7, and once a term in Year 8. The students completed the questionnaires by hand writing their answers.	Method of analysis Using the IBM SPSS Statistics Software, the results of the analysis of Linkert scale responses in the Control and Active group were analysed using descriptive statistics options. This organised the data as sets of quantitative comparative data in frequencies and percentages for both active and control groups. This made any differences in the control and active conditions easier to identify. Qualitative quotes and paraphrased student opinions were used also identified and used to answer this research question (Table 53 p. 426 Appendix E)	Product I conducted descriptive statistics to identify differences between the active and control responses. Tables that were used to compare the student questionnaire responses of the active and control group throughout the study. This made clear any differences in the control and active conditions outcomes. Charts were also used to show the percentage differences of yes responses, a bit responses and no responses between the control and active group at different points during the study. (Data Analysis Section Tables 27 and 28 p. 230 & 236 and Figures 27-35, p. 236-248) The charts made it easier to identify patterns in the data when comparing the active and control group.
	Mixed	Lesson Observations Lesson observations were conducted by me during my PPA time. I had a Science timetable of every class involved in the study during my PPAs. I used this as a schedule to regularly (either once a week or once a fortnight) go into the Science lessons to conduct lesson observations (I would conduct student interviews during the same visit – see above). In each year of the study there was one class that were harder to observe as I had no PPA during their lessons. In that case I asked a colleague to cover for me whilst I conducted the lesson observation. This enabled me to observe a large number of lessons without it having an impact on my full-time teaching commitment at the school. The lessons were observed using the lesson observation sheet (Appendix G p. 491 and 501) and the recording of my observations was hand written word on a lesson observation sheet.	Method: I used the lesson observation form that can be found in Appendix G p. 555 & p.565 this enabled me to tick if I observed WM activities happening or saw evidence of it in the students' books. I also recorded whether I observed the start, middle or end of the lesson (as I thought at the start of the study that this may have a bearing on whether I observed WM activities, as the study progressed however it was clear this had no impact on the results of my observations). I could also record if students or the teacher were talking about memory as part of the lesson or if it was a normal way of teaching lesson - control group (this latter part of the table did not generate however meaningful data that is included in the study).	Product I conducted descriptive statistics to identify differences between the active and control responses. The outcome of the data I collated from lesson observations was a frequency count recording of whether I could see evidence of the WM activities being used in the lesson; in combination with time sampling the part of the lesson I was observing (i.e., start, middle or end) was used. The lesson observation enabled me to see if the active group and the control group were both experiencing the activities specified in the method of this study. This also meant I could record the number of lesson observations made and any observations of the use of WM activities observed within the lessons can be found in the Data Analysis Chapter on section 4.4.4.
b.	Quantitative	Science attainment assessments: Science attainment data was gathered from students completing a base line science skills assessment, science homework tasks, science written summative tests, and science investigative skills assessments. The assessments were marked by the class teachers, and moderated during science team meetings. The data was inputted on a	Method: The data from the student's Lucid Recall test results was exported to a MS Excel document as raw data. This was done to make the data easier to manipulate and export into IBM SPSS The data were then analysed using IBM SPSS Statistics Software This made comparisons between the control and active group easier to make.	I conducted inferential statistical tests to see differences on my quantitative data – the Science attainment data. The product of the inferential statistics: the independent t-tests, enabled the non-significant and significant differences in the means (using the t values and the p-values) between the control group and the active group to be identified

	Mixed	progress tracking sheet on the school's information management system. The students were marked using in house assessment criteria that equates to GCSE grades (if they continue to make similar progress year on year) but with their year group as the first number for example 7.1, 7.2 or 8.4. This supplied the pre- and post-test data that could be used with inferential statistics to measure the impact of the activities to develop WM compared to the normal way of teaching.	The attainment data was inputted into a marksheet on the school's information management system by the teachers taking part in this study. This marksheet attainment data was exported to MS Excel spreadsheet so it could be used with the IBM SPSS Statistics Software. This made comparisons between the control and active group easier to make. The data were then analysed using IBM SPSS Statistics Software	I also conducted inferential statistics to see if there was a relationship between post-test WM assessments and Science attainment. The product of the correlation tests the r-value and the p-values enabled the non-significant and significant relationships to be identified for the control and the active group. Comparisons of the numbers of non-significant and significant relationships could be conducted to compare the control and the active condition. Regression line analysis on IBM SPS was also used to produce evidence on the strength of the relationship between WM assessments and end of Y7 report grade The product of the inferential statistics: the dependent t-tests, enabled the non-significant and significant differences in the means between the pre and post-test WM assessment and Science attainment data to be identified (using the t values and the p-values)for the control group and the active group. The differences in the p-values for the significant differences were analysed to give tentative evidence to support findings (as the independent t-tests had many non-significant differences). Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figures 27-29 p.236-238; Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 30-31 p.241 & 242; Dependent t-test results Tables 124-137 in Appendix H p. 561-580, Tables 18-20 p. 212-218)
	Mixed	Student interviews: see above	For Method See Above	For Product See Above
	Mixed	Student Questionnaires: see above	For Method See Above	For Product See Above
	Mixed	Lesson Observations – see above	For Method See Above	For Product See Above
c.	Mixed	Student interviews – see above	For Method See Above	For Product See Above
	Mixed	Student Questionnaires – see above	For Method See Above	For Product See Above
	Mixed	Lesson Observations – see above	For Method See Above	For Product See Above
d.	Mixed	Student interviews- see above	For Method See Above	For Product See Above

	Mixed	Student Questionnaires – see above	For Method See Above	For Product See Above
	Mixed	Lesson Observations – see above	For Method See Above	For Product See Above
e.	Mixed	Student interviews – see above	For Method See Above	For Product See Above
	Mixed	Student Questionnaires – see above	For Method See Above	For Product See Above
	Mixed	Lesson Observations – see above	For Method See Above	For Product See Above
Transparency Data collection	Mixed	Science Teaching Assistant Questionnaires (Appendix G p.487 and p. 497): The teaching assistants who were supporting the classes included in the study completed a printed questionnaire by hand writing their responses. One questionnaire was completed each year.	Method of analysis: There were a small number of responses to this questionnaire as only 3-4 of the classes had a teaching assistant with them each year of the study. So, the frequency and the collation of comments was done by myself by recording on a MS Excel Spreadsheet. This meant the data was easy to draw any conclusions from.	Product: Tables recording the number of times the teaching assistants responded to each question for the scaled questions and a column to record comments see Tables 86 & 87 on pages 465 & 467 in Appendix F. This meant the data was easy to draw any conclusions from.
	Mixed	Science Teacher Questionnaires (Appendix G p. 483 and p.492) : The science teachers who were teaching the students involved in the study completed a printed questionnaire once a term in science department meetings by hand writing their responses.	Method of analysis: There were a small number of responses to this questionnaire as only 6 teachers completing this questionnaire 2-3 times each year of the study. So, the frequency and the collation of comments was done by myself by recording on a MS Excel Spreadsheet. This meant the data was easy to draw any conclusions from.	Product: Tables recording the number of times the teachers responded to each question for the scaled questions and comments were generated see Tables 67-85 p. 451-464 in Appendix F, this data if further analysed in the analysis chapter section 4.3.5 p.246. This meant the data was easy to draw any conclusions from.
	Mixed	Whole Staff Questionnaires (Appendix G p. 489 an p.499): These were completed by all school staff (excluding caretakers, cleaners, and canteen staff) once a year in a staff meeting. The staff completed a printed questionnaire by hand writing their responses.	Method of analysis: Using the IBM SPSS Statistics Software, the results of the analysis of Linkert scale responses in the Whole Staff Questionnaires (Appendix G p. 489 and p. 499) were analysed using descriptive statistics options. This organised the data as sets of quantitative comparative data in frequencies and percentages for teaching staff and support	Product Tables were used to compare the staff questionnaire responses. Tables 88-94 p.469-480 in Appendix F and p.311-316 &Tables 138 & 139, p. 582 & 584 Appendix H in the analysis section. Tables of the information shared as quotes from staff Tables 90,92,94 p. 472, 475, 489 in Appendix F. This made the analysis of the responses easier to synthesise.

			staff for both years. This made any differences or patterns in the data easier to identify. Qualitative quotes and staff opinions were recorded separately. This meant the responses was easy to draw any conclusions from. The impact of the information shared in the quotes from staff on the outcome of the study were discussed in the analysis chapter section 4.5.6 p. 581 and Tables 138 & 139 p. 582 & 584 Appendix H and the discussion	

3.3.4 Quantitative Data

There are three main areas of quantitative data collection these are outlined in Table 5. Table 5 shows explicitly how each research question will be answered and the quantitative data that was collected to answer the research questions. The Lucid Recall Working Memory Battery of Tests (St. Clair-Thompson, 2015) are the only tests that the student participants undertook that were not part of the normal school science assessment of progress. The data collected from Lucid Recall (St. Clair-Thompson, 2015) is used to answer research question (a). These tests are standardised this indicates that they enabled me to collate reliable data. The justification of selecting Lucid Recall as the test used in the research is explored in detail in the section 3.3.6. The remaining quantitative data is the Science attainment assessment (baseline and throughout both years); this was a range of assessments including science investigations testing investigative science skills, science homework and summative tests. These have grading rubrics or detailed mark schemes that ensure a good level of inter-rated reliability. The data collected from the Science attainment assessments is used to answer research question (b).

I also used their end of year report grade in Year 7 and 8 to answer research question (b). This is another outcome variable. This is a teacher generated grade that takes into account all the facets of the student's science attainment and their consistent performance in lessons. Teachers are given guidelines to ensure they are consistent in their grading of students; hence it is a reliable measure of attainment. I considered using an external standardised test; however, this would have been challenging as the school where the research was undertaken is an academy. Schools with academy status are able to set their own KS3 curriculum that does not have to follow the national curriculum. Although the KS3 curriculum broadly follows the national curriculum it was different enough to make any external test's reliability questionable. Furthermore, the ethics of exposing the students to more Science tests in addition to their normal assessments would have been hard to justify. So, the decision was taken to use the existing Science assessments that are bespoke to the school's own grading system.

Justification for Using Lucid Recall as the Working Memory Test

The most important aspects of the Working Memory testing are that:

- the tests are standardised
- the tests measure the aspects of WM that would be needed to ensure the rigor and validity of the study
- the tests can be administered to large numbers of students relatively quickly
- there is a minimal cost implication

The Working Memory Tests must include a test for auditory processing working memory (Verbal Working Memory), visual spatial working memory and the central executive. The best fit for all these conditions is Lucid Recall (St. Clair-Thompson, 2015).

3.3.5 Justification of using quantitative data to answer specific aspects of the research questions with links to the WM model in the literature that is used in this thesis

I am using the widely accepted Baddeley and Hitch WM model that is used by other researchers in an education context e.g., (Alloway, 2009; Alloway & Gathercole, 2009; Au, et al., 2015). However to summarise; the model includes the phonological loop and audio-visual sketchpad these parts bring information in from the environment via auditory and visual pathways. Also included is the episodic buffer (a conduit to hold onto information for the central executive that has no storage capacity of its' own); these three pass this information to the central executive that has the role of processing the information. This model states that WM is the mental note pad students have in their minds where they hold and manipulate information over a short period (Baddeley A. , 2014). Hence, WM is how students in a classroom take in and process new information; in order to learn that new information.

This model was chosen in part for its ability to fit within the pragmatic paradigm and the naturalistic-experimental design frame that it is embedded in this paradigm (Feilzer, 2010). A pragmatic paradigm allowed me to be focused on taking action to investigate my research questions without needing to take either a realist or constructivist stance (Weaver, 2018). The Baddeley and Hitch model of WM is one that can be applied to how students learn in the classroom. Enabling the research to take place in a classroom having an impact on KS3 students Science attainment. This enabled me to focus on the research in the classroom; namely the activities to develop WM, their impact on KS3 Students' WM and hence KS Science attainment.

The WM test chosen was Lucid Recall as it is designed using the Baddeley and Hitch WM model (St. Clair-Thompson, 2015). This test is used in schools to quantify and standardised students' WM and would give real world data that is usually used by teachers to inform their teaching. Hence, this test fits well into the pragmatic paradigm and naturalistic-experimental design frame. The summative Science attainment data is also quantitative, and once again used in a real-world context to track the progress of Science attainment in students throughout Key Stage 3. This again fits well into the pragmatic paradigm and naturalistic-experimental design frame. Whereupon, the research question is being researched in a real-world context and with the stance that the knowledge currently accepted may have to be rejected as the outcomes of the research are analysed and reported (Weaver, 2018).

3.3.6 Justification for using Lucid Recall as the WM Test – in the context of the Baddeley and Hitch Model and the ontological, epistemological, design framework and theoretical assumptions of this research

Table 6 Justification for using the Lucid Recall Test in this doctorate study.

Research World View	World View Justified for this research study	Justification of using Lucid Recall as WM Test
Ontology	Pragmatic Paradigm	Lucid Recall was designed using the Baddeley and Hitch Model as the construct of WM being tested (St. Clair-Thompson, 2015) by a researcher who has used the Baddeley and Hitch Model to frame their own WM training research (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010). This research can hence have at its' centre the WM activities created to develop WM and how these may impact on KS3 students WM and Science attainment on multifaceted levels. The Lucid Recall enables the WM of students to be measured within the constructs of the model which are linked to how the students learn in the classroom.
Epistemology	Neither : I view knowledge from both a realism and constructivism standpoint. This enables me to look at the impact of	The Lucid Recall Test of WM enables the realism standpoint to be taken for this part of the data collection; as it provides a quantitative measure of

	WM activities I have created to develop WM on many different levels	the WM of students assessed. This is valid due to the Lucid Recall Assessment & the research both being based on the Baddeley and Hitch Model of WM (Baddeley & Hitch, 1974; St. Clair-Thompson, 2015)
Design Framework	Naturalistic-Experimental Design: This fits well within a pragmatic paradigm and the epistemological stance. As it enables me to analyse the multileveled impact of the WM activities, I have created to develop WM in a real-world context not a laboratory. Leading to being able to see the impact of my research in the real world on the social issue of underachievement (the socio-economic gap)	The Lucid Recall Test of WM enables quantitative data to be collated so that I can establish if the WM activities created to develop WM are having a quantitatively measurable difference between the active and control group conditions; as it provides a quantitative measure of the WM of students assessed. This is valid due to the Lucid Recall Assessment & the research both being based on the Baddeley and Hitch Model of WM (Baddeley & Hitch, 1974; St. Clair-Thompson, 2015)
Theoretical Assumptions	The students are all able to access the tests and assessments used to gather	The students will all be able to access and complete the Lucid Recall Test, making the data comparable

	WM and Science attainment data. So, the data will be comparable. The Science teachers in the active group will generally deliver the WM activities I have created to develop WM in their lessons with minimal variation of delivery between teachers. The Science teachers in the control group will generally deliver “normal way of teaching” lessons with minima variation of delivery between teachers. The students will interpret the questions I ask them in the student interviews in a similar way The students will interpret the questions being asked in the student questionnaire in a similar way The myriad of other confounding variables that I am unable to measure for	

	students in and out of school will have a similar impact on each student's WM.	

3.3.7 Justification for using Perception Data from Questionnaires & Qualitative Data

Table 5 shows explicitly how the perception data and qualitative data is used to answer research questions c, d and e. Enabling complex questions about the impact of activities to develop WM on students' perception of far transfer, learning and metacognition. One of the advantages of working within a pragmatic paradigm and the naturalistic-experimental design frame that it is embedded in this paradigm (Feilzer, 2010) is that the research takes place in a real-word context not in a laboratory (Weaver, 2018). Furthermore, the pragmatic paradigm enables mixed methods research (Johnson & Onwuegbuzie, 2004) that enables the many strata of the activities to develop working memory within KS3 Science lessons to be investigated in full with the participants of the study (Feilzer, 2010). So, there is not only the quantitative data for example demonstrating if WM has or has not improved and if the Science assessment data means are different when comparing the control and active group. But there is also the perception data; do the students think that the activities to improve WM are having an impact on their learning in Science and their learning in other subjects, do they think that the activities to improve WM do improve their memory. Furthermore, there is the deeper strata of the qualitative data about the students' opinions on the WM activities, do they think they are helping them learn or do other activities they do in Science lesson have more of an impact on their learning. This is the deeper real world context strata that will enable me to get a more holistic answer to my thesis question.

Table 5 explains how each of the qualitative data for each of the research question (c), (d) and (e) were collected and subsequently analysed. There were three overarching aims of using qualitative data alongside the quantitative data in the research. Firstly, the qualitative data gave the opportunity of non-cognitive (research questions (c) and (d)) and metacognitive evidence (research question (e)) to be used to assess the impact of the different lesson structures on the students' WM (see Table 5) and Science attainment (research question (d)) (Table 5) from a different non-quantitative perspective. Secondly, the qualitative data was important (alongside the quantitative data) in triangulating the measurable cognitive impact of the differing lesson structures (research question (b)), with the student's non-cognitive and metacognitive experiences and observations, and the student's general and personal perception of WM, learning, intelligence, and memory, within those differing lesson structures (research questions (a), (c), (d) and (e)).

The third aim was to provide a high transparency within the study. The qualitative data provided transparency of the student participants experience of WM and memory activities in the school environment throughout the time span of the research. As well as, providing transparency of the staff's personal perception of WM, learning, and the staff's opinion on the efficacy of the lesson structure to improve WM. The latter was an important area to gather data on; because this enabled me to assess the presence of any expectancy effect. If present this would need to be considered when discussing the outcomes of the study. Qualitative data gathering techniques will be discussed in this chapter with a view to evaluating the various qualitative data gathering tools a summary of these is also found in Table 5. This will lead to the justification of the techniques that I have chosen to investigate the research questions centred around WM, learning and Science attainment.

3.3.8 Justification that there are aspects of WM and Science attainment that cannot be captured through quantitative data and only through qualitative data

The pragmatic paradigm, epistemological stance of being neither realist nor constructivist embedded within the paradigm and having a naturalistic-experimental design framework; has enabled me to look beyond the straightforward quantitative answer to the research questions. As discussed earlier I have many theoretical assumptions that also have shaped the research (For further discussion please see section 3.1.3 Justification of naturalistic-experimental design framework). These theoretical assumptions look at aspects of WM and Science attainment that I am unable to capture with quantitative data from tests and assessment alone. Hence, this meant that this study was also able to look at the impact of the activities I have created to develop WM on KS3 students WM and Science attainment on different levels. Including the student's perception of their memory, intelligence, and learning (Tables 6 & 7).

Justification for using qualitative techniques (and perception gathering data) to answer specific aspects of the research questions

The research study is based on two groups of students one group experiencing the activities I have developed to increase WM in KS3 Science lessons and the other group experiencing a normal way of teaching Science without the activities to develop WM. It was important to gather data on how the different group's lessons were being delivered by teachers and how these were perceived by the active and control group (Table 5). This enabled me to ascertain if the active and control groups were experiencing different lesson structures. This would also highlight any variability in delivery of the lessons between the three classes within each group. Furthermore, it would demonstrate to me if the students in the active group perceived the activities to develop WM differently to the control group perceived their normal way of teaching lesson structure.

In order to gather data on how the different lesson structures were being delivered, variability within them and student perception of them; I could have used observation, interviews, group interview or focus groups or questionnaires (Thomas, 2017). I was working full-time at the school where the research was taking place. This meant I had good access to the lessons, students, teachers, and teaching assistants. The only constraint was time. I also had to fulfil my teaching and leadership role within the Science department during the day. Similarly, the timetabling of preparation planning and assessment time (PPA) limited access to some of the classes where the research was being conducted. These time constraints ruled out the use of group interviews and focus groups and limited the use of data gathering techniques to observation, interviews, and questionnaires.

Observation is important in educational research; and can be unstructured or structured (Cohen, 2017). Unstructured observation is much more in line with interpretivist view points and immersive research design frames that solely use qualitative data. Table 5 outline the use of lesson observation to provide insight and context when answering my research questions. I must within my experiment design frame be a disinterested observer. In order to establish if the activities in the active group and the normal lessons in the control group were being delivered in the way the I intended and to ascertain the variability within the active and control classes. To do this effectively, it was important that I observed the three active group classes and three control group classes regularly (the aim was once a fortnight for each class). Due to the time constraints I chose to do short structured observations. This would allow me enough time to observe two different classes in the same PPA hour (if the timetable had two lessons running concurrently).

Structured observation often uses time to shape the outcome for example duration recording and interval recording. However, because I had time constraints the data, I collated from lesson observations was using a form of frequency count recording in combination with time sampling. I was looking for the use of WM activities within the lesson (listening activities, reading sheets, writing down what has been learned). This meant for a maximum of 10 minutes I would observe the lesson, resources being used and look at students' books to ascertain how the active and control group lesson structures were being delivered (Appendix G p. 491, 501).

I also used interviews to gather data on how the different lesson structures were being delivered, variability within them and student perception of them. Interviews can be structured, unstructured or semi structured and can be conducted in different ways; online chat, skype (or other video call platforms), telephone or face to face (Thomas, 2017). Unstructured interviews usually take the form of a conversation so need time and space to conduct. Furthermore, unstructured interviews are led by the interviewee and what they wish to discuss hence, are usually used by researchers that have an interpretivist stance.

I used the semi-structured form of interview with a small number of predetermined questions (Appendix G p.491 & 501) and the opportunity to explore further student responses. I did not favour the inflexible approach of the structured interview, that would not allow further questioning to follow up student responses nor a response to subtle shifts in body language. Interviews of students took place in their science classroom as a one-to-one conversation to avoid the risky shift phenomenon observed when humans are in groups (Cohen, 2017). To be time efficient I conducted the interviews after an observation. The questions asked of the students were:

- Do you do memory activities in your science class?
- If yes: Do you think doing memory activities in your science class is useful for your learning?
- If yes: Why
- Do you find it easy, medium, or difficult to learn in Science?
- Why?
- What activities do you do in Science that help you learn the most?

Table 7 outlines the theoretical assumptions I have made that led to the construction of the questions, and the gathering of perception and qualitative data that measure aspects of WM and Science attainment that cannot be measured quantitatively using the Lucid Recall WM Test or the Science assessments as measures of Science attainment.

Table 7 The theoretical assumptions that led to the questions in asked in the Student Interview

Interview Question	Theoretical Assumption which informed the question design	Further clarification
Do you do memory activities in your science class?		I did not assume that students would know they

<table>
<tr><td></td><td rowspan="6">• Learning being a change in the LTM caused by changes to (or efficiency of) the students’ WM
• Changes in WM can be measured qualitatively using questions in interviews questionnaires
• Any changes to the LTM within a Science lesson are directly linked to the WM based on the Baddeley and Hitch Model (Figure 4)
• The changes to WM and LTM will be noticeable explicitly to the students
• Students would have the ability to recognise that their memory and intelligence may be changing
• Students can recognise if they are learning more information
• Students know when they are finding it harder or easier to learn
• Students are able to understand and able to state orally which activities have helped them learn the most</td><td>were completing activities to develop WM</td></tr>
<tr><td>If yes: Do you think doing memory activities in your science class is useful for your learning?</td><td></td></tr>
<tr><td>If yes: Why</td><td></td></tr>
<tr><td>Do you find it easy, medium, or difficult to learn in Science?</td><td></td></tr>
<tr><td>Why?</td><td></td></tr>
<tr><td>What activities do you do in Science that help you learn the most?</td><td></td></tr>
</table>

These questions were chosen to gather data on student experiences and opinions. To ascertain if the active and control group were being taught science with two different lessons structures; and the variability of the lesson structure within the three classes. To compare the active and control group opinion and perceptions of learning Science. This enabled qualitative student non-cognitive and metacognitive data to be collected. The students interviewed were chosen at random from the students who had not yet been interviewed in that academic year. I was not able to interview every student in every class but I was be able to interview 95 of the 171 students participating, the students were selected at random producing a representative sample.

I also used questionnaires to establish how the active and control lessons were being delivered, variability within them and student perception of them. Questionnaires were used with the students, Science teachers of the students and teaching assistants that supported students in Science classes where the research took place. Paper based questionnaires were used throughout the research. Student access to complete an online questionnaire as a class would need additional logistics of booking laptops or IT rooms for classes this would have been an additional work request on already hardworking teachers. Students completing the form online themselves would have had a lower response rate then the teacher delivering the paper questionnaire in a lesson, with minimum additional work for the teacher.

The student questionnaire comprises of a quantitative Linkert scale and free response question. The students completed a minimum of two questionnaires a year (Appendix G p.485 & 495); in addition to the student interviews. The aim of the questionnaires was to gather data on students’ experiences of memory activities throughout the school, their experience of the lesson structure as well as their opinions and perceptions of WM, learning and intelligence. So, I rejected questionnaire styles such as multiple choice, ranked order and constant sum method in favour of the rating scale questionnaire style (Cohen, 2017). I chose The Linkert Scale so the students would have to choose to Yes, A bit or No to a list of nine statements but would have the opportunity for a free written comment at the end of the questionnaire. From the onset I purposely kept the questionnaire short and easy to fill in with no writing required just tick the boxes. Preliminary questionnaires were trialled with a class of Year 7s in the previous year to test accessibility. As a result, I changed the scaled responses from strongly agree, agree, neutral, disagree, strongly disagree to Yes, A bit, No. I also changed the order of the statements moving the "I have a good memory" and "I am intelligent" statements to the end of the questionnaire. The students who trialled the questionnaire felt that those questions were the most difficult for them to answer and so would put off students completing the questionnaire if they remained at the top. So, the final questionnaire had the statements in this order:

- I can remember information from lessons really well
- I think that having a good memory is important for learning
- I think having a good memory is part of being intelligent
- In science lessons I do activities to practice using my memory
- In other subjects I do activities to practice using my memory
- I use the memory skills I practice in Science in other subjects
- I am learning new information and skills in Science
- I have a good memory
- I am intelligent

Tables 7 & 8 outline the theoretical assumptions I have made that led to the construction of the questions, and the gathering of perception and qualitative data that measure aspects of WM and Science attainment that cannot be measured quantitatively using the Lucid Recall WM Test or the Science assessments as measures of Science attainment.

Table 8 The theoretical assumptions made that led to the questions being asked in the Student Questionnaire

<table>
<tr><th>Questionnaire Question</th><th>Theoretical Assumption which informed the question design</th><th>Further clarification</th></tr>
<tr><td>I can remember information from lessons really well</td><td rowspan="6">• Learning being a change in the LTM caused by changes to (or efficiency of) the students' WM
• Changes in WM can be measured qualitatively using questions in interviews questionnaires
• Any changes to the LTM within a Science lesson are directly linked to the WM based on the Baddeley and Hitch Model (Figure 4)
• The changes to WM and LTM will be noticeable explicitly to the students
• Students would have the ability to recognise that their memory and intelligence may be changing
• Students can recognise if they are learning more information
• Students know when they are finding it harder or easier to learn
• Students are able to understand and able to state orally which activities have helped them learn the most</td><td>I did not assume that students would know they were completing activities to develop WM</td></tr>
<tr><td>I think that having a good memory is important for learning</td><td></td></tr>
<tr><td>I think having a good memory is part of being intelligent</td><td></td></tr>
<tr><td>In science lessons I do activities to practice using my memory</td><td></td></tr>
<tr><td>In other subjects I do activities to practice using my memory</td><td></td></tr>
<tr><td>I use the memory skills I practice in Science in other subjects</td><td></td></tr>
</table>

I am learning new information and skills in Science	• All students would be able to have a level of metacognition that enabled them to reflect on their learning at a comparable level	
I have a good memory		
I am intelligent		

Another purpose of combining the data gathering techniques of interviews and questionnaires with the students was to avoid (or identify and take account of in the findings) prestige bias in the interview or questionnaire responses (Thomas, 2017).

The science teachers and science teaching assistants completed questionnaires to establish how the different lesson structures were being delivered, variability within them and teacher and teaching assistant perception of them. Questionnaires were chosen as interviews would have been too time consuming. Paper questionnaires were used for science teachers, as they were issued during one of the weekly science meetings. This maximised the response rate. If the questionnaire was online then it was more likely to be overlooked, due to the vast number of emails that school staff receive every day. The research questionnaire is not vital to the day to day running of the school and hence would not be prioritised. The science teaching assistants were given their questionnaire in the teaching assistant meeting for the same reasons. Furthermore, teaching assistants have limited access to computers during their working day meaning a paper-based questionnaire would get a better response rate.

The aim of the science teacher and teaching assistant questionnaires (Appendix G p. 483, 487, 492 & 497) meant using a combination of rating scale questions linked to how frequently memory activities occurred in the classroom and The Linkert Scale used to obtain data on the opinions of the lesson structure to develop WM. This would enable me to account for the expectancy effect or the Hawthorne effect within the findings. The choice of time frequencies to tick can be seen below:

- Practically every lesson
- 5/6 lessons per fortnight
- 4-3/6 lessons per fortnight
- 2-1/6 lessons per fortnight
- 0/6 lessons per fortnight

The teachers of the active and control group were asked to respond to this list of statements (a minimum of twice a year) (Table 9 shows an explanation of the use of each question):

- I follow the lesson structure to develop working memory
- I do 3 listening activities in a lesson
- The students read the differentiated reading sheets
- The students write down what they have learned with only the sentence starters to support them if needed
- I give students examples of memory techniques to help them with activities in the lesson
- After the listening activities I review the students' progress explicitly
- Students are given opportunities to think about their memory and how it helps them to learn

Allowing data to be gathered about lesson structure delivery and variability.

Table 9 The justification of each question asked in the Science Teacher questionnaire

Questionnaire Question	Justification of question
I follow the lesson structure to develop working memory	This was part of the WM activities that I designed to be delivered to students. However, the teachers taking part in the study were

	not being asked by their line manager to complete the study. So, they could choose to not follow part or all of the WM activities the active group classes should have been exposed to. Hence this question enables me to ascertain if the three active groups had a comparable experience and that the control group were not being exposed to the WM activities by teachers who thought they were so effective all students should be exposed to them. This enabled me to take into account another of the many confounding variables in this study
I do 3 listening activities in a lesson	See above
The students read the differentiated reading sheets	See above
The students write down what they have learned with only the sentence starters to support them if needed	See above
I give students examples of memory techniques to help them with activities in the lesson	Teachers were not asked to do this as part of the activities to develop WM, however on discussion with the teachers prior to the research it was clear that some teachers completed additional activities that may impact on WM and attainment of students and

	hence data should be collated so that holistic picture is built of what may have caused differences in WM and attainment.
After the listening activities I review the students' progress explicitly	Teachers were not asked to do this as part of the activities to develop WM, however on discussion with the teachers prior to the research it was clear that some teachers completed additional activities that may impact on WM and attainment of students and hence data should be collated so that holistic picture is built of what may have caused differences in WM and attainment.
Students are given opportunities to think about their memory and how it helps them to learn	Teachers were not asked to do this as part of the activities to develop WM, however on discussion with the teachers prior to the research it was clear that some teachers completed additional activities that may impact on WM and attainment of students and hence data should be collated so that holistic picture is built of what may have caused differences in WM and attainment.

The teaching assistants were asked to respond to this list of statements (once a year):

- I support students with the differentiated reading sheets
- I support students with the writing down what they have learned at the end of the lesson

The teaching assistants and teachers were asked to respond to The Linkert Scale statements by ticking :

- Strongly Disagree
- Disagree
- Neutral
- Agree

- Strongly Agree

The teaching assistants responded to these statements:

- I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods
- The students I support have seen an improvement in their memory skills since the start of the research study

Whereas the teachers responded to these statements:

- I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods
- I use activities to develop working memory with other year groups

The questionnaires were trialled with science teachers and teaching assistants. The aim of the trial was to determine if the questionnaire was clear, precise, collected the data it was intended to and did not take a long time to complete. The feedback on the questionnaires was positive so no changes were made.

The final piece of data collection aimed to collate the school staffs' use and or observation of memory activities throughout the school with the students participating in the study. As well as, their opinions and perceptions of WM, learning and the lesson structure to develop WM. Interviews and group interviews were rejected in favour of paper-based questionnaires due to time constraints, although the I recognise that these methods of data collection would have been useful to increase the transparency of the study.

Paper questionnaires were used with the whole staff because I presented to the staff once a year during the research as part of a whole staff meeting. This ensured informed consent of the staff before asking them to complete the questionnaire – either during the meeting (five minutes was allowed in the agenda for this) or in their own time or they could choose not to complete the questionnaire. This also maximised response rate as most staff chose to complete the questionnaire during the meeting. I chose not to do this electronically because if the questionnaire was online then it was more likely to be overlooked, due to the vast number of emails that school staff receive every day. The research questionnaire is not vital to the day to day running of the school and hence would not be prioritised. Furthermore, some staff have limited access to computers during their working day meaning a paper-based questionnaire would get a better response rate.

The whole staff had a scale rating questionnaire (Appendix G p. 489 & 499) with a list of job roles to circle how they come into contact with the students/participants of the study (e.g., teacher, tutor, caretaker) and using The Linkert Scale to enable a Yes, No, Don't know response to the statements below:

- I have heard of working memory
- I am aware that working memory is linked to learning
- I have spoken to Year 7 students this year informally about memory
- I have led an activity in a class, tutor time or assembly about memory this year with Year 7s
- I use working memory activities with the current Year 7 students
- I think developing working memory has a positive impact on learning
- I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students
- This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (not Year 7)
- I think the science lesson structure to develop working memory has the same impact as traditional teaching methods
- I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods

This questionnaire would enable the triangulation of data from lesson observations, student questionnaires to analyse the leakage of WM activities into the control group from other subject areas within the school. It also enables triangulation of attitude to the efficacy of the lesson structure to develop WM with science teachers and teaching assistants. This gives transparency in order to consider any expectancy or Hawthorne effects that should be discussed in the findings. Finally, this gives transparency to the research study, because the data has been collated (with time constraints) on the memory and WM experiences of the students participating in the study over two years.

3.4 Procedure

An outline of the procedure for year one and year two of the study can be seen in Figures 14 and 15 respectively.

Figure 14 An outline of the procedure for the first year of the doctoral research

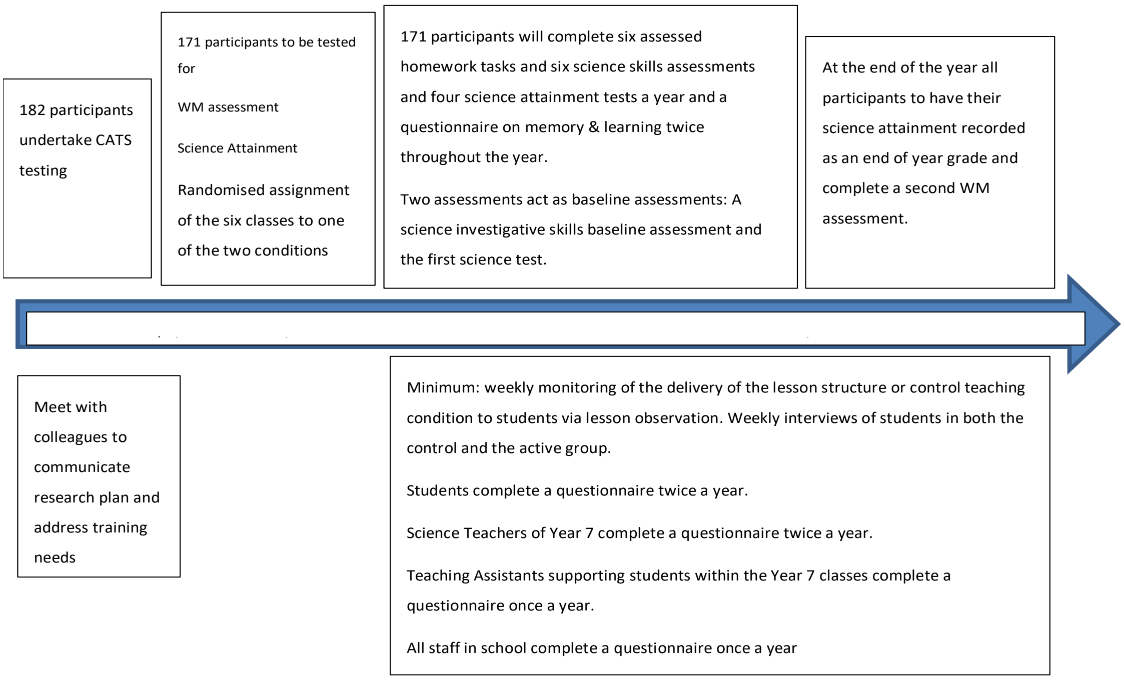
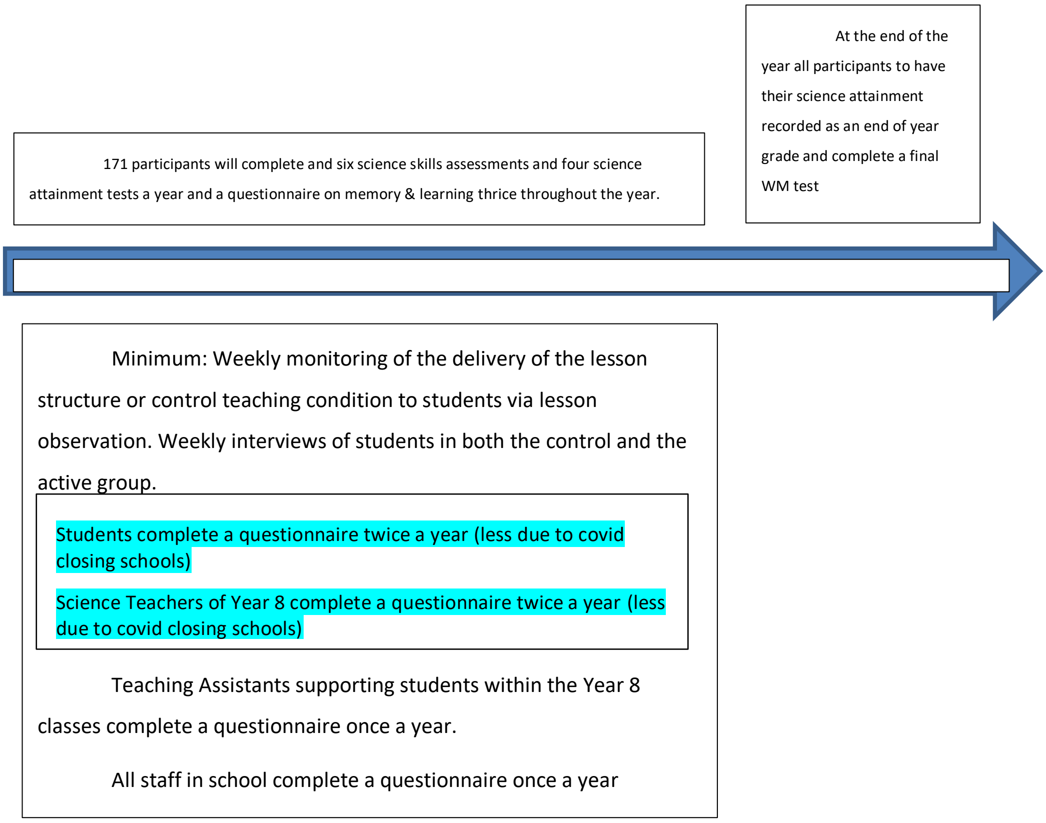


Figure 15 An outline of the procedure for the second year of the doctoral research



Firstly the 182 participants were placed in six teaching groups (classes), this was complete from May to June 2018 (Method and Methodology section 3.2 Participants). This was carried out as part of the school preparations for the students starting in Year Seven, September 2018. The 182 participants undertook CATS tests (Lohman & Smith, 2014) during July 2018. This is testing that Year Seven students are always subjected to so will not be subject to the opt out option that all students will have as part of the ethics of this research study.

Due to six students leaving the school and five students choosing to not opt themselves into the study the number of participants reduced to 171 in total. The 171 participants had Lucid Recall WM Testing (St. Clair-Thompson, 2015) in the IT suites at the school ran by a volunteer who has been trained to run Lucid Recall. This testing was conducted before the research started in early October 2018 and repeated in June 2019 & June 2020. After the first Lucid Recall Test the teaching groups were randomly allocated to active group or the control group. There were 3 classes in each group. The CATS scores, age and gender were analysed to ensure the active and control group were comparable (Method and Methodology section 3.2 Participants).

Over the next two years the active and control group were delivered the science curriculum for Year 7 and Year 8 with different lesson structures (Figure 16) shows the two conditions of this research). The active group teachers delivered the lesson structure outlined in Figure 17 the control group were delivered the Science lessons using traditional teaching methods for representative of the Science teaching in the school.

Figure 16 The two different conditions of the doctoral research study

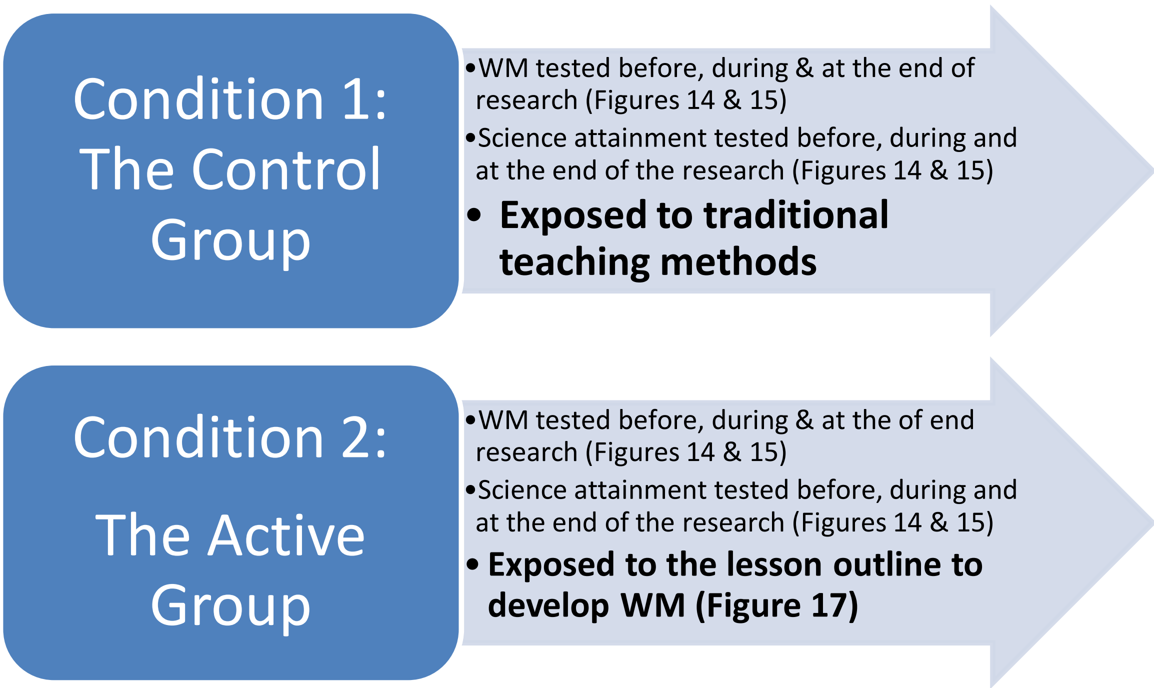


Figure 17:A diagram of the lesson outline to develop working memory used by the Science teachers of the classes in the active group.

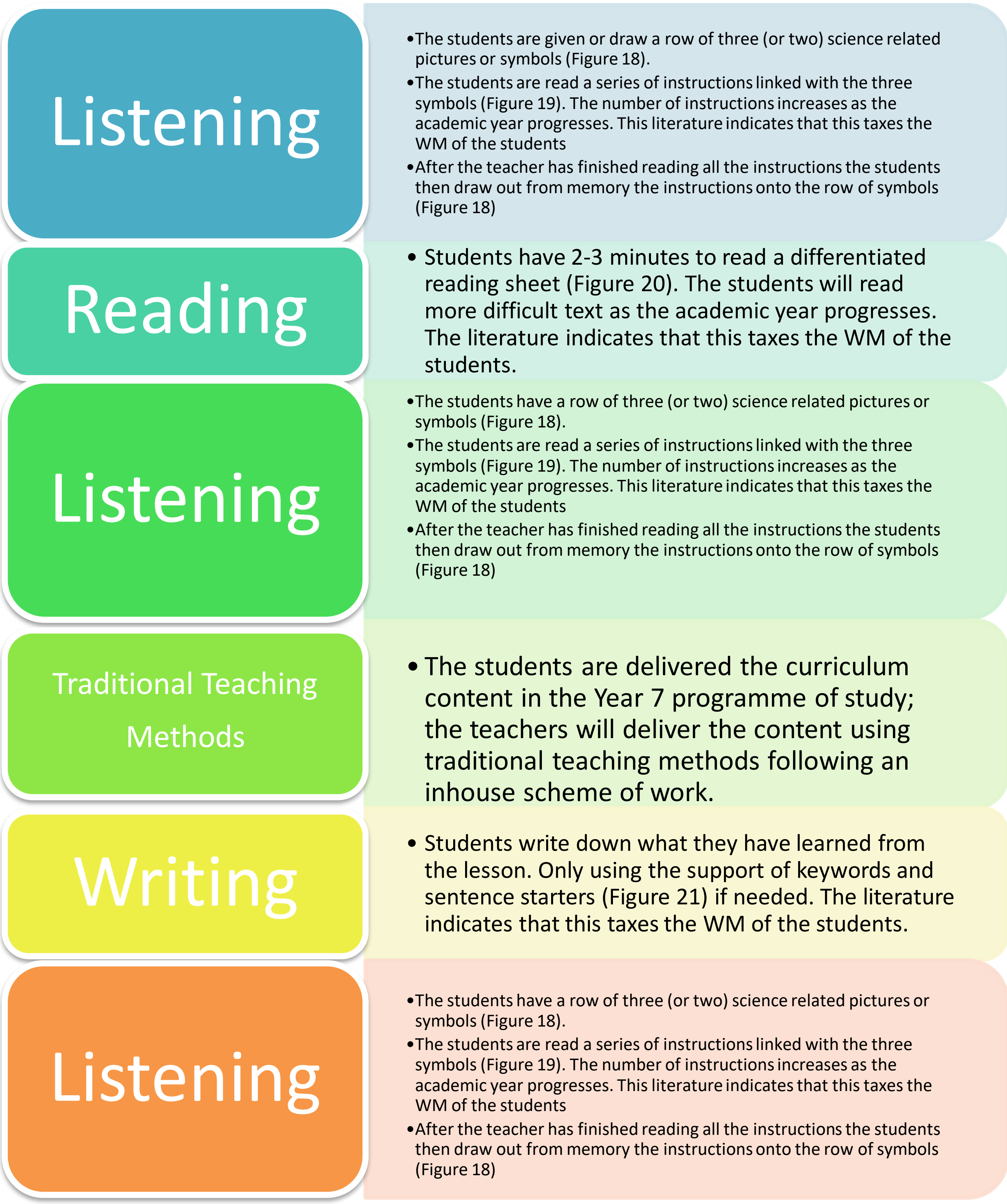


Figure 18: An example of the sheet, students use in the lesson; with different symbols, this is used during the listening activity

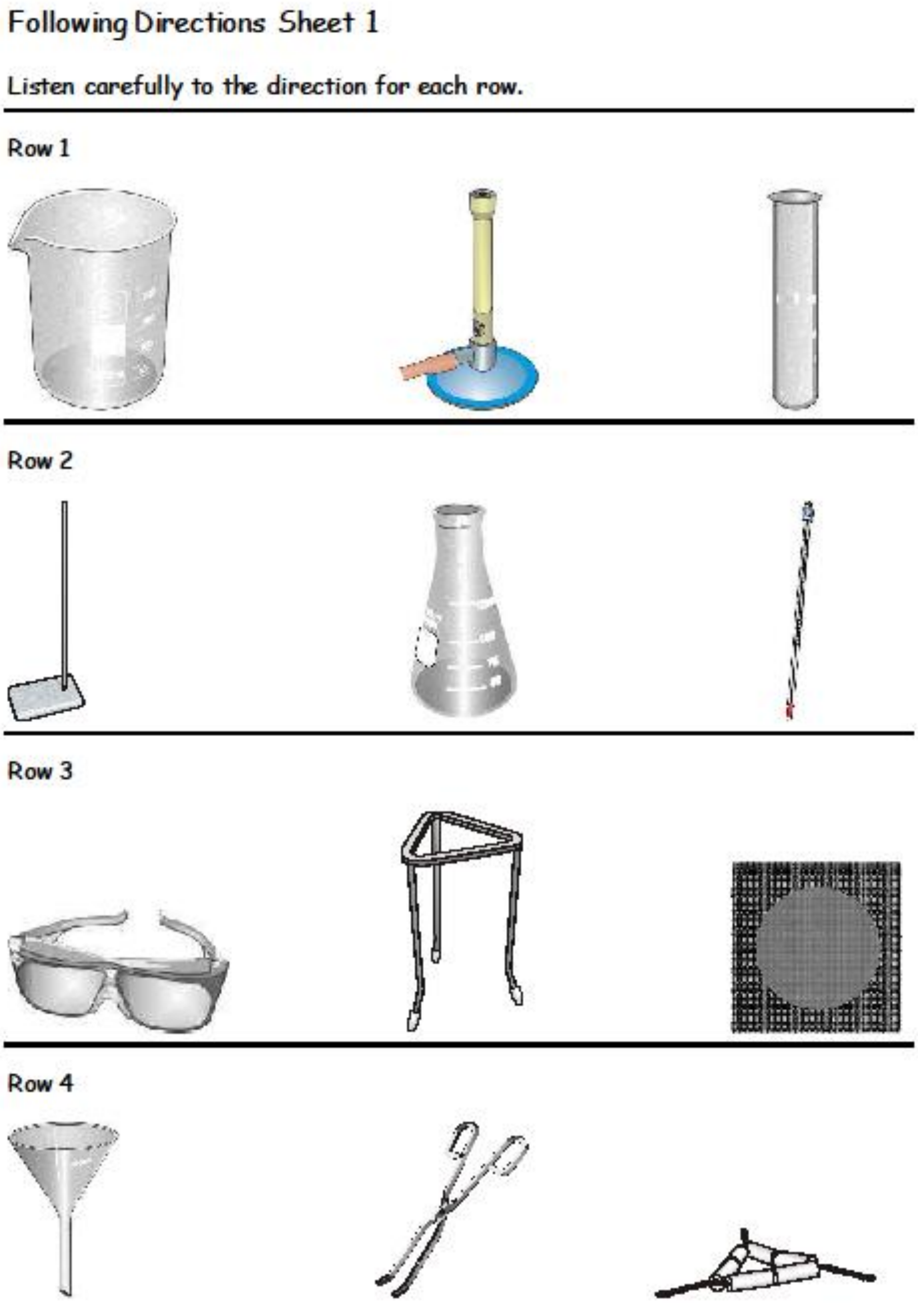


Figure 19: An example set of instructions to match the symbols in Figure 18 for the listening activities referred to in Figure 17.

Page 1 Following Directions (Two Step instructions)

Row 1: Draw some water in the beaker and a flame coming out of the Bunsen Burner

- Draw smoke coming out of the boiling tube and draw a dotted line along the bottom of the beaker
- Draw a tripod standing over the Bunsen Burner and put a gauze on top of the tripod

Row 2:

- Add a boss and clamp to the clamp stand
- Draw a beaker around the thermometer and draw a line to show water in the beaker
- Draw a dotted line between the top of the conical flask and the bottom of the clamp stand

Row 3

- Draw googly eyes on the goggles and a Bunsen underneath the tripod
- Draw a vertical line between the gauze and the tripod
- Add eyebrows above your googly eyes and draw a smiley face in the middle of the gauze

Row 4

- Draw a beaker underneath the funnel and liquid dripping in the beaker
- Put a stone in the tongs and draw a horizontal line underneath the clay pipe triangle
- Join the top of the funnel to the bottom of the clay pipe triangle with a wiggly line

Figure 20: An example of the differentiated reading sheets used in the reading section of the lesson structure to develop WM (Figure 17).

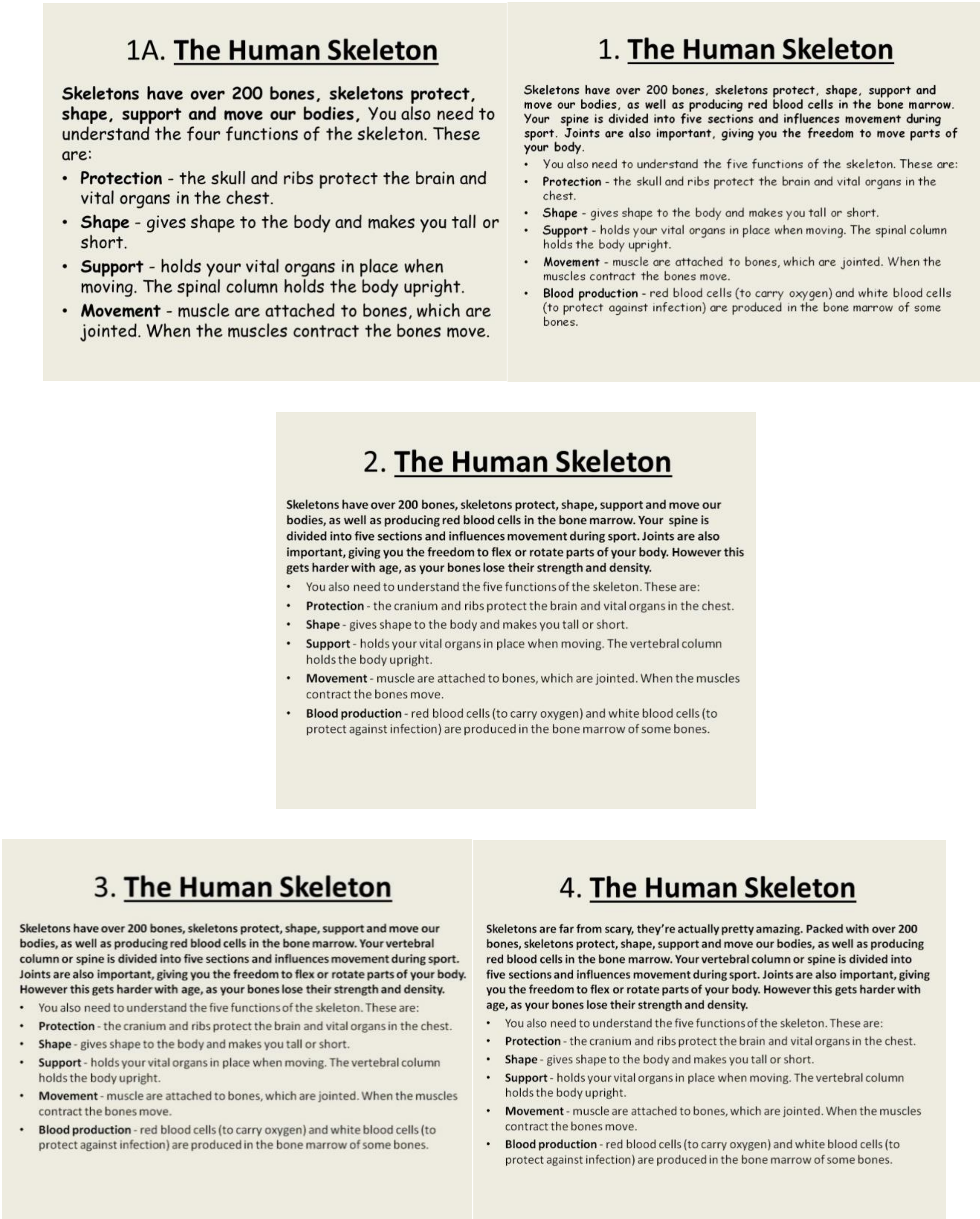
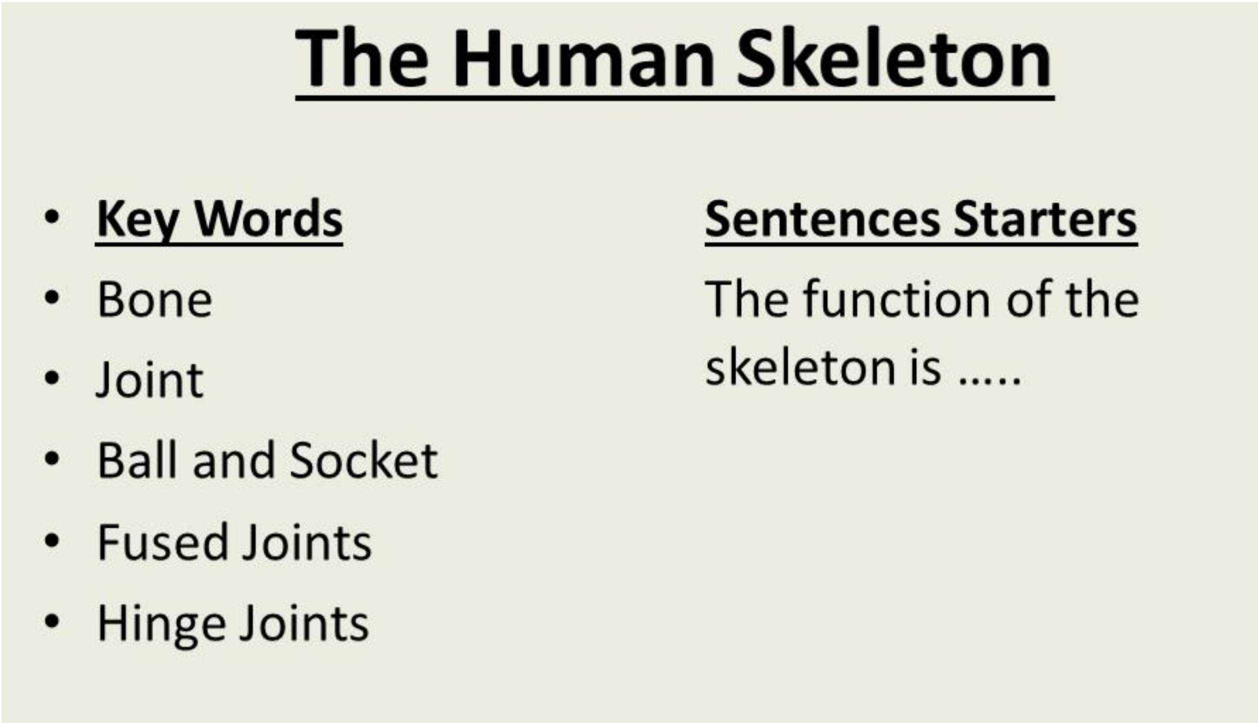


Figure 21: An example of the sentence starters used to provide differentiated learning support to students during the writing section of the lesson structure to develop WM.



All 171 participants were regularly assessed on their Science attainment (Figures 14 and 15). This included a baseline Science investigative skills assessment and a summative test complete at the beginning of the research period. This was part of the participants' normal assessment of their progress in Science throughout years seven and eight. Students were asked to fill out a questionnaire twice in the first year of the study and thrice in the second year of the study. These were completed during a Science lesson.

I observed the lessons of the participant's six Science classes on a weekly basis (the number of lessons observed varied from week to week due to time and timetabling constraints). Each lesson observation was a maximum of ten minutes. I then, conducted a short semi-structured interview with two students in the lesson they had just observed.

The Science teachers of the participants were asked to fill out questionnaires. This was completed twice in the first year of the study and thrice in the second year of the study. This was done during Science Department Meetings. The Science teaching assistants filled out a questionnaire one a year. The whole school staff filled out a questionnaire once a year. The majority of staff completed the questionnaire during the staff meeting, others returned it to me at a later date.

3.4.1 Development of the Working Memory Intervention Materials

I started researching working memory because of a conversation I had with an educational psychologist who was visiting the secondary school where I worked. I had explained an issue I was having with my then 5-year-old son's behaviour and he mentioned auditory processing might have been an issue. This conversation sparked an exchange of emails and further discussions with this educational psychologist about the prevalence of auditory processing disorder and other WM deficits in children and its implications for their ability to learn.

The educational psychologist was working with a deputy head in a nearby secondary school. The deputy head had set up intervention groups for Years 7, 8 and 9 using activities to develop working memory. These included listening activities using a set of books called *The Central Auditory Processing Kit* (Mokhemar, 1999), reading activities and writing activities.

The students in this intervention group had been selected based on their low CAT scores and low reading skills and their below average writing ability. The intervention took the students out of their modern foreign languages lessons to do this intervention work (3 hours per week). The lessons were based on humanities topics but with the listening, reading, and writing activities to develop the students' working memory embedded within every lesson.

I went to visit this secondary school, watched the WM intervention lessons, and saw evidence of the huge improvements of the students from November to July. Students who were functionally illiterate at the start of the intervention had increased their reading age by years in just 8 months and could now write sentences independently. This was changing the lives of these students and their life chances in the future. I was inspired to take this idea back to my secondary school.

I spoke to my headteacher in July 2013 about setting up a similar intervention group focusing on our next cohort of Year 7s. However, the headteacher did not want to go down this route as there is a strong ethos in the school of teaching mixed ability classes. So, I decided to trial it with my Year 7 mixed ability Science class in the 2013-2014 academic year. I decided to approach this trial as an action research study. I used *The Central Auditory Processing Kit* (Mokhemar, 1999) listening activities three times in a lesson. In addition, I aimed to include a science specific reading activity and writing activity for each lesson.

This meant I wrote differentiated reading sheets for every Year 7 Science lesson and wrote sentence starters for every Year 7 Science lesson. These reading sheets were based on the learning outcomes of that lesson (Figure 20) as were the sentence starters (Figure 21) so students with weaker literacy skills could access the writing activity at the end of every lesson.

The Central Auditory Processing Kit (Mokhemar, 1999) is set out as a series of double page spreads. The first page has three or four rows of three random shapes or numbers or letters. For example, row one might have a square, diamond and the letter "T." On the opposite page there will be a set of instructions to read out. For example, "Tick the square and draw a circle around the letter "T" ". The page with the rows of shapes etc would be copied and given to the students. The book starts out with 2 step instructions and increases as you go through the book in both the number and complexity of the steps of instructions. (You can see examples on this web page: Resources for Therapists, Teachers, Parents and Carers | Central Auditory Processing Kit | Winslow (winslowresources.com))

In my Year 7 Science lessons in 2013-2014 I would read out the instructions and the students had to listen and remember them. Then when I said "Off you go" the students would have to draw the instructions they remembered on the photocopied page with the relevant row. However, as I started to read the literature it became clear that the listening activities would have a greater impact on students WM and hence Science attainment if they were domain specific. So, two years on, in 2015 I developed my own Science specific rows of science equipment (Figure 18) and instructions (Figure 19) based on *The Central Auditory Processing Kit* (Mokhemar, 1999). After the first listening activity the students would collect a differentiated reading sheet and read in silence for 2-4 minutes. Then they would replace the reading sheet return to their seats and complete a second listening activity.

The students then took part in the activities planned to help them achieve the learning outcomes of that lesson. Usually including practical activities and student modelling. Then 10 minutes before the end of the lesson they would sit down and write down what they had learned today. The students who had weak literacy skills were supported with the sentence starters sheet (Figure 21). Then just before the end of the lesson a third listening activity was completed. This lesson structure is outlined in Figure 17.

I analysed the action research study results by comparing my Science class attainment with the attainment of the other five science classes in Year 7. I was surprised to see what a big difference there was in the student attainment. My Year 7 class had significantly higher attainment compared to the other five classes. So, I extended the action research study in two ways. In 2014-2015, all the Year 7 classes had the WM activities in their lessons (I led this as part of my deputy head of Science role). My original trial class now in Year 8 would have a different teacher who would carry on using the WM activities with the Year 8 class (so differentiated reading sheets and sentence starters were developed for every Science lesson in Year 8).

At the end of 2014-2015 I analysed the results. I compared the Year 7 Science attainment to the prior year's data (excluding my Y7 data). The Year 7 Science attainment was significantly higher in 2014-2015 compared to the previous year. I also compared the Year 8 class with the Year 8 Science attainment for the rest of the year. Again, the Year 8 class had significantly higher attainment but also greater than their difference in attainment in Year 7. This indicated that the impact of the WM activities on Science attainment may be accumulative.

I then went to the literature to see if I could enrich further the activities to develop WM within my Science lessons. I was confident that activities to develop WM in classrooms would be a well-researched area. Disappointingly I found that there were very few published studies (Figures 1-3) and none focussed on Science. This is what led me to write the PhD proposal for this study. I had seen these activities were having a large impact on student attainment. These activities were also cheap and simple to implement into lessons. Completing a PhD study would be a way of shining a spotlight on the developing WM as a way of increasing Science attainment in secondary schools.

This PhD study has an active group that experience the working memory activities that I developed using the materials in Figures 18-21. Section 2.5 (Working memory is important for learning) and section 2.7 (Working memory is an important differentiator of students' attainment) of the literature review the everyday classroom activities of listening, reading, and writing (see Figures 18-21) as ways of learning are discussed. The literature supports the idea that WM function is required to take in information by listening and reading and commit this information to your long-term memory (Figure 11). The literature also supports the idea that WM function is required to recall information from the long-term memory and write this down in the students' own words.

3.5 Analysis

The benefits of working within a pragmatic paradigm and the naturalistic-experimental design frame that it is embedded in this paradigm (Feilzer, 2010) is that the research takes place in a real-word context not in a laboratory (Weaver, 2018). Furthermore, the pragmatic paradigm enables mixed methods research (Johnson & Onwuegbuzie, 2004) that enables the many strata of the activities to develop working memory within KS3 Science lessons to be investigated in full with the participants of the study (Feilzer, 2010). So, within this mixed methods approach there is quantitative data and the perception data and purely qualitative have to all be analysed appropriately within a real-world context. This has led to the quantitative data being analysed statistically, the perception data being analysed with descriptive statistics to be able to drill down and demonstrate the impact of the WM activities on the metacognition of the participants of this study. Finally, the qualitative data has been analysed by reading and re-reading the responses to open questions and interview questions, and the constant comparative manner. This enables an even deeper stratum of the impact of the activities to develop WM on the WM and learning of the students to be analysed. Overall, these multi-strata analysis will enable me to find a more holistic answer to my thesis question. Table 5 demonstrate where this has been used in data collection and that the categories of the final coding and detailed examples can be seen found in (Appendices D & E).

I recognise that using a mixed-methods approach to data gathering meant a complex approach to data analysis using a range of methods. The quantitative data can be analysed using a range of widely available software packages including Microsoft Excel, IBM SPSS, and the free statistics software R. The perception data and some of the qualitative data analysis for closed scale response questions can be quantified and hence analysed using quantitative analysis tools.

On the other hand, responses to open questions from questionnaires and interviews or other sources of qualitative data must be analysed in a different way. The qualitative data gathered in an interpretivist design frame is more likely to lend itself to be analysed using construct mapping, thick description, and grounded theory (Thomas, 2017). Whereas, it would be more appropriate to analysis the qualitative data gathered from open questions for this doctoral research- being set within an experiment design frame – using the constant-comparative method. The constant comparative method, although usually used with research from an interpretivist standpoint is appropriate for this doctoral research. This is because the qualitative data involves reading and re-reading the responses to the open questions from the student interviews. I can then identify general themes within the responses. The responses are then coded using categories shaped by these themes. The student responses for example were categorised into metacognitive and non-(meta)cognitive or different learning activities in the class room. Table 5 demonstrate where this has been used in data collection and that the categories of the final coding and detailed examples can be seen found in Appendices D and E. These frequency tables can be seen on p 224 in the data analysis chapter Table 22 p. 224 and Table 25 p.227 (the raw data Tables 57-62 p. 434-440 can be found in Appendix E).

The quantitative data was analysed using the statistic software IBM SPSS Version 26. Analysis was completed to identify and correlations on the following using inferential statistics tests

- between WM and Science Attainment
- between change in WM and Science Attainment

3.5.1 Justification of analysis using correlation statistical tests

Furthermore, inferential statistics were used to analyse the relationship between WM post-test assessment scores and Science assessment attainment. Correlation coefficient tests were This undertaken to see if there was a relationship between student WM and their science attainment. In addition to which if those two variables were found to correlate for both groups, then which group the control or the active group has the strongest correlation. This type of analysis would enable me to answer RQ b.

3.5.2 Justification of analysis using t-tests statistics to compare two means

Independent t-tests were conducted on each of the means of the active and control groups for each of the quantitative measures e.g., WM test data (baseline and end of Year Seven), Science test data, Science investigative skills assessment data, Science homework data, and end of year Science report data. This was conducted to see if the control and the active group had statistically significantly different means. If the control and the active groups' means were statistically significantly different this would indicate that the activities to develop WM used in Science lessons or the normal way of teaching were having an impact on the WM and or Science attainment.

Dependent t-tests were conducted on the means of the baseline WM tests and the end of Year Seven WM tests, baseline science investigative skills and the other investigative skills tests, and

Year Seven test 1 and Year 7 test 2, 3 and 4 and Year Eight tests 1 and 2 and the end of year seven report grade, and the end of year eight report grade. These were done to see if the control and the active groups had statistically significantly different WM test or attainment data compared to the start of the research study. If they were statistically significant different then I looked at the t and p values to see if the it was the control or the active group who had improved or decreased the most. The former being an indicator that one of the conditions tested may be having an impact on the students within that condition.

Justification of analysis of perception data and qualitative data

Basic differential statistics were used to analyse the scaled responses to the closed questions that were part of the student questionnaires and the student interviews. The open questions from student interviews and questionnaires were analysed using the constant comparative method. The responses were grouped into categories of activities (i.e., for the student response to the interview question “What activities to you do in Science that help you learn the most?”). Alternatively, the responses from the students to the other open questions were grouped into metacognitive responses and non-(meta)cognitive responses. Where further analysis was necessary these subdivided into neutral, positive, and negative responses.

Basic differential statistics were used to analyse the scaled responses to the closed questions that were part of the Science teacher, Science teaching assistant and staff questionnaires. The open questions were not analysed as there were relatively few. Instead, the direct quotes have been included within the data analysis and discussion chapter of the doctoral thesis. The direct quotes have been used to reinforce or show a juxtaposition between the overall pattern and the response to open questions.

The validity of the research outcomes relies on the data gathering and my ability to control the confounding variables. The data gathering used one external test to measure WM. Lucid Recall (St. Clair-Thompson, 2015) has construct validity as a test as it measures the test using the constructs within the accepted and used in this research Baddeley and Hitch model of WM (pp17-21

St. Clair-Thompson, 2015). This doctoral research has a myriad of confounding variables acting on the participants within the school and as part of each student's homelife. I recognise that they are unable to control the majority of the confounding variables. However, with the gathering of extensive qualitative data I have sort to address this issue by having a high level of transparency throughout the study. This being taken into account the findings of the research have internal validity and could well tend towards having external validity.

I strived to gather data both quantitative and qualitative data. The aim being to have effective triangulation of the cognitive effect, the non-cognitive effect and impact on participant opinions and perspectives of the differing lesson structures on WM and hence Science attainment. This in turn was integral into enabling valid conclusions to be drawn. The different types of data gave a much fuller and clearer picture of the differing effects of the two types of lesson structure of the WM and learning of the active group compared to that of the control group.

Overall, the reliability of the quantitative data, triangulated with the qualitative data being able to provide transparency so the findings from this study would have more validity and credence.

3.6 Ethics

Early on in the planning of the research; I considered the ethics procedures and permissions that would need to be sort to conduct the research. The research would take place in a secondary school in East Devon, England, UK. The procedures to gain ethics approval for research in a UK school can be time consuming and if amendments need to made to any part of the research design this can delay the start of the research. I put in place advance planning and a six-month buffer for the date they were aiming to obtain ethics approval for the research. If this careful planning and allowing for time delays had not been taken into consideration significant changes may have had to be made to the length of the study. This could have significantly curtailed the ability to obtain data at specific points within an academic year, and ultimately may have meant reducing the study to one academic year rather than two.

I am a PhD student of The Graduate School for Education at The University of Exeter. Hence, the ethics permission had to be sort from The Social Sciences and International Studies Ethics Committee (SSIS Ethics Committee). A detailed form had to be completed and submitted to the SSIS Ethics Committee. Details included establishing that the research was not funded by, or didn't use data from, either the NHS or Ministry of Defence; nor did the research involve participants aged sixteen or over who are unable to give informed consent. This meant that an external ethics committee was not required. I also outlined the background of the research, within the context of published literature on WM, leaning and Science attainment.

The SSIS Ethics Committee required details of the research design and how that would be executed within the school. The emphasis was on these main areas, the informed nature of participation, the voluntary nature of participation, assessment of possible harm to the participants and myself, special arrangements, data storage and data protection.

In order to assure the informed nature of the study, the Science teachers delivering the differing lessons were given a presentation on the research and an information sheet to read. Parents of the students were also given a letter and an information sheet. Furthermore, the students who were invited to take part in the study were given a presentation about the research and talked through the information sheet. The whole school staff were given an annual presentation on the research that included all the details of the information sheet, further information was made available for staff if required.

The voluntary nature of participation in the research study was assured by all participants and their parents being given an information sheet (or for whole school staff a presentation which delivered the same information) about the research to read before they gave informed consent. The active participants gave written consent to take part in the study. The science teachers delivering the differing lesson structures had an opt into the research form. However, the parents had a form that enabled them to opt their child out of the research whereas the student had an opt into the research form. This demonstrates that I want to ensure the transparency of the voluntary nature of the participation of the students. The form had my contact details of the and those of my lead PhD supervisor. So, participants or their parents could contact the University as well as the school if they had any concerns about the research that they felt unable to raise with myself directly. The students who chose to opt out of the research (there were no students whose parents opted them out) as per the SSIS ethics committee approval; remained in their class but any data obtained specifically for the study (questionnaires or WM test data) would be excluded and not included in any data analysis.

Ethically, it was important for me to consider possible harm to the participants and the myself. The majority of tests undertaken were conducted normally within a school year; apart from the Working Memory testing. So, it was not anticipated that the child participants would become distressed during the standard testing. The WM test administrators are trained in delivery and are aware to move on if a student cannot answer a question. The school were aware of the intervention and had systems in place to support students if that was required. Special arrangements were considered where for a very small number of students, they would not be able to access a test or questionnaire entirely independently. Where this was the case, a teaching assistant supported the student to access a test or questionnaire. I was not at risk from harm by conducting this research study.

I considered the ethics of data storage and protection. All data was collected in line with current data protection and GDPR rules and laws. This research study involves obtaining both quantitative and qualitative data from the participants. Confidentiality and anonymity were maintained by individuals' personal details being linked to raw data using numbers; the teachers of each of the classes will be referred to as Teacher 1, Teacher 2, Teacher 3, Teacher 4, Teacher 5, and Teacher 6. Each member of staff who fills out a questionnaire will be referred to as Staff 1, Staff 2 …etc. The name and personal details of each member of staff (i.e., who is Teacher 1 or Staff 1) will be kept in MS Excel Workbook (different to that of the one containing the student data and staff data from the tests, questionnaires etc) that will be password protected and kept on The University of Exeter's U:drive.

The student participants' confidentiality and anonymity were maintained by linking their personal details and their raw data by numbering each of the students; i.e., Student 1, Student 2, Student 3 …etc. This will ensure that no personal data that is controlled by the school will be taken out of the school. The personal details of each of the students will be in a MS Excel Workbook (different to that of the one containing the student data and staff data from the tests, questionnaires etc) that will be password protected and kept on The University of Exeter's U:drive.

To be clear there will be a minimum of two password protected MS Excel Workbooks one with the identity of the participants and the ***word and number*** they have been attributed and another MS Excel Workbook with the data from the participants but with the participants themselves anonymised. The latter of these documents will be held in a password protected file on The University of Exeter's U:drive. The former will be held with the school personal data on the secure school computer (as normal for student data at school). This will ensure that no personal data that is controlled by the school will be taken out of the school. The majority of the data used for this research would be collected and used to inform teaching and track student progress in Science. The following data would be normally held on the School Information Management System (SIMS) this data is password protected.

- CATS tests
- Baseline test in Science
- Summative Science Assessments
- Report Data

I exported the data from SIMS to at MS Excel Workbooks anonymised the data as outlined above to enable tracking of progress and descriptive and inferential statistical analysis of the data. This MS Excel Workbooks will be held on The University of Exeter (U:Drive) and so will be password protected. To protect the security of the data by password protecting not only the server but also the MS Excel Workbooks. The data being especially collected for the research is the Lucid Recall Working Memory Tests, data from the student and staff questionnaires, and student interviews will be held in separate password protected files. All the data on computer files will be kept indefinitely for use in future research. All raw data on paper will be kept to the end of the thesis and then destroyed. No data that identifies individual participants or the institution used will ever be placed in the thesis, or in any other document or presentation written or given as a direct or indirect result of this research.

It is important to consider a declaration of interests surrounding this research. The information that the school were partially funding the research (I subsidised the funding from SLE and consultancy work done for the school) was freely available to all participants. I have for many years pursued evidence-based teaching research that could demonstrate the importance of Working Memory in Science attainment and the possibility that developing Working Memory could increase Science attainment. The gap in the has led me to plan and undertake their own research into this area. The school where the research was conducted fully supported the research but are not biased by its' outcomes. The school wants to ensure that whatever the outcome of the research; it was conducted with a holistic view of what the student participants experience hence giving the study transparency and hence, validity.

The results will be used to demonstrate the role of developing Working Memory in learning Science and hence Science attainment. The outcome of the research will be shared with colleagues within the school, and with colleagues from some teaching school alliances (this may go on to spark further evidence-based teaching research projects in other schools or across whole teaching school alliances). The research may also be published in relevant journals. Ethically the user engagement and feedback from the research must also be discussed. Neither the student nor the adult participants of this study were in the design, executing and reporting of the study. However, participants were able to change the information given in questionnaires or interviews at any time throughout the study. If requested, a summary of the findings of the research was given to any participants at the end of each academic year.

Chapter Four Data Analysis

The data analysis of all the data for this doctoral study can be found in Chapter Four and Appendices E ,F & H. The Chapter Four Data Analysis includes only the data that will focus on the key findings from the data, in order to answer RQs a-e. This has been done to ensure the presentation of both the key findings and evidence supporting the key findings were clear.

4.1 Analysis of Pre and Post Working Memory Tests and Science Attainment Assessments

4.1.1 Introduction

The students in the study had both their WM and their Science attainment measured at specific points during the two-year study. Table One shows the different components of WM and Science attainment that were assessed with additional information about time of the assessments. All quantitative data was analysed using statistics software IBM SPSS Version 26.

Table 10 The components of WM or Science Attainment students were assessed for during the two-year PhD Research Study

Component of Study Being Assessed	Detail of Assessment	Further Information
Working Memory	Word Recall	A standardised component of the Lucid Recall Working Memory Test (St. Clair-Thompson, 2015) Completed at the start of Year 7 and the end of Year 7Test (St. Clair-Thompson, 2015)
Working Memory	Pattern Recall	A standardised component of the Lucid Recall Working Memory Test (St. Clair-Thompson, 2015) Completed at the start of Year 7 and the end of Year 7Test (St. Clair-Thompson, 2015)

Working Memory	Counting Recall	A standardised component of the Lucid Recall Working Memory Test (St. Clair-Thompson, 2015) Completed at the start of Year 7 and the end of Year 7Test (St. Clair-Thompson, 2015)
Working Memory	Composite	A standardised component of the Lucid Recall Working Memory Test (St. Clair-Thompson, 2015) Completed at the start of Year 7 and the end of Year 7Test (St. Clair-Thompson, 2015)
Working Memory	Processing	A standardised component of the Lucid Recall Working Memory Test (St. Clair-Thompson, 2015) Completed at the start of Year 7 and the end of Year 7Test (St. Clair-Thompson, 2015)
Science	Investigation Planning Skills	Six completed in Year 7 (including a baseline investigation) & three or four in Year 8 (Covid)
Science	Investigation Obtaining Evidence Skills	Six completed in Year 7 (including a baseline investigation) & three or four in Year 8 (Covid)
Science	Investigation Analysing Data Skills	Six completed in Year 7 (including a baseline investigation) & three or four in Year 8 (due to Covid)
Science	Investigation Evaluation Skills	Six completed in Year 7 (including a baseline investigation) & three or four in Year 8 (due to Covid)
Science	Physics Assessed Home Work	Year 7 Only
Science	Chemistry Assessed Home Work	Year 7 Only
Science	Biology Assessed Home Work	Year 7 Only
Science	Test 1	Year 7 & Year 8
Science	Test 2	Year 7 & Year 8
Science	Test 3	Year 7 only (due to Covid)
Science	End of Year Test	Year 7 only (due to Covid)

Science	End of Year Report Grade	Year 7 & Year 8

4.1.2 A Comparison of Pre-test and Post-test means and standard deviations of the WM and Science attainment components assessed

Firstly, descriptive statistics were used to compare the pre-test means and standard deviations in tabular form (Tables 11, 95-100 p.504-508) for the active and control group. I did this to see if there were any differences between the active and control group for the pre-test WM tests and Science attainment assessments. This was the baseline to compare the post-test data. . The pre-test descriptive data for had similar means and overlapping standard deviations demonstrating that at the start of the study there was no significant difference between the active and control group.

Secondly, the pretest descriptive statistics were compared to the post-test WM tests and Science attainment assessments (Tables 11-12 and Tables 95-100 p. 504-508 Appendix H). The descriptive statistics do not show a significant difference between the WM test assessments and the Science attainment assessments of the control group and the active group when comparing pre-test and post-test data. These are key findings in answering RQ a.

Table 11 The Working Memory Assessments pre-test & post-test means and standard deviations for both the control group and the active group

WM Component Assessed	Pre-test Control Group			Post-test Control Group			Pre-test Active Group			Post-test Active group		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Word Recall	83	103.868	13.500	82	105.122	14.446	79	104.354	10.550	82	104.976	12.850
Pattern Recall	83	97.554	10.986	82	100.537	11.239	79	98.987	11.157	82	102.756	9.964
Counting Recall	83	100.615	17.0836	82	104.317	18.766	79	100.051	16.235	82	104.610	18.588
WM Composite	83	102.241	12.928	82	105.293	14.841	79	102.595	10.484	82	105.940	12.034
WM Processing Speed	83	92.699	11.472	81	95.901	12.027	78	94.756	10.332	81	96.580	11.101

4.1.3 Comparing the means of the Post-test Working Memory Tests Assessments independent (unpaired) t-tests in order to answer RQ a.

Inferential statistics were undertaken, using the independent (unpaired) t-test to analyse if there was a statistically significant difference between the means of the control and active group for the post-test WM assessments. This allowed me to see to gather inferential statistical findings to answer RQ a. The outcome of the independent (unpaired t-test) are in Table 12.

Table 12 The results of an independent (unpaired t-test) on the post-test results of the WM test assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
WM Test Component Assessed	M	SD	M	SD			
Word Recall	105.122	14.446	104.976	12.850	162	-0.069	.945
Pattern Recall	100.537	11.239	102.756	9.964	162	1.338	.183
Counting Recall	104.317	18.766	104.610	18.588	162	0.100	.920
WM Composite	105.293	14.842	105.939	12.034	162	0.306	.760
WM Processing Speed	95.901	12.027	96.580	11.101	160	0.373	.709

There is no statistically significant difference between the post-test means of the WM assessment of the active group compared to the control group. The outcome of the independent t-tests for WM assessment comparing the post-test means of the control and active group indicate that activities to develop WM have no significant impact on the WM assessment scores. Hence, this indicates that WM may not be significantly improved in students completing activities to develop

WM in their Science lessons compared to the students who had the normal way of teaching. The independent t-test findings are listed in detail in Appendix H p 509-517. This is a key finding in helping to answer RQ a. and will be discussed in Chapter 5 along with possible explanations for this finding.

However, the findings from the data analysis to answer RQ b. do indicate that the active group have some conceptual links (a correlation) in cognition between WM and students' knowledge & understanding of science. This is addressed in Sections 4.1.5 - 4.1.9.

4.1.4 Comparing the means of the Post-test Science Attainment Assessments independent (unpaired) t-tests in order to answer RQ b.

Inferential statistics were undertaken, using the independent (unpaired) t-test to analyse the science attainment data to see if there was a statistically significant difference between the means of the control and active group for the post-test Science attainment assessments. This allowed me to see to gather inferential statistical findings to answer RQ b. that specifically pertains to the activities to develop WM increasing Science attainment.

The tables detailing the full the outcomes of the independent t-tests between the means of the control and the active groups post-test Science attainment can be found in Appendix H (Tables 101-106 p.509-517). These data provide some of the evidence to answer RQ b.

The inferential statistics reveal a large number of non-significant differences between the means of the Science attainment assessments of the active and control group (Tables 101-106 p.509-517, Figures 22-24, p.195-196). This data was important to include to demonstrate that any significant findings must be treated cautiously and tentatively when drawing conclusions. There are few significant differences in the attainment means between the active group and the control group. Where significant differences in the attainment means are present, both the active and the control group have similar numbers of higher significantly different means for different assessments within summative tests, Science investigative skills and chemistry homework. Figures 22-24, p.195-196 detail the number of non-significant differences in the means, the number of significant differences where the control group had a higher mean compared to the active group, or active group had a higher mean compared to the control group.

Figures 22-24, p.195-196 demonstrate the lack of significantly different means for one condition compared to the other (active or control). The lack of significantly different suggests that the activities to develop WM are not having a significant impact on Science attainment. Hence, any conclusions drawn from any significant findings will have to be tentative and treated cautiously. The impact of these non-significant findings in relation to RQ b. are discussed in Chapter 5.

Figure 22 A bar chart of the numbers of non-significant differences in means, and significantly different means (higher for active or the control groups) for summative test and end of year grade attainment when independent t-tests were conducted.

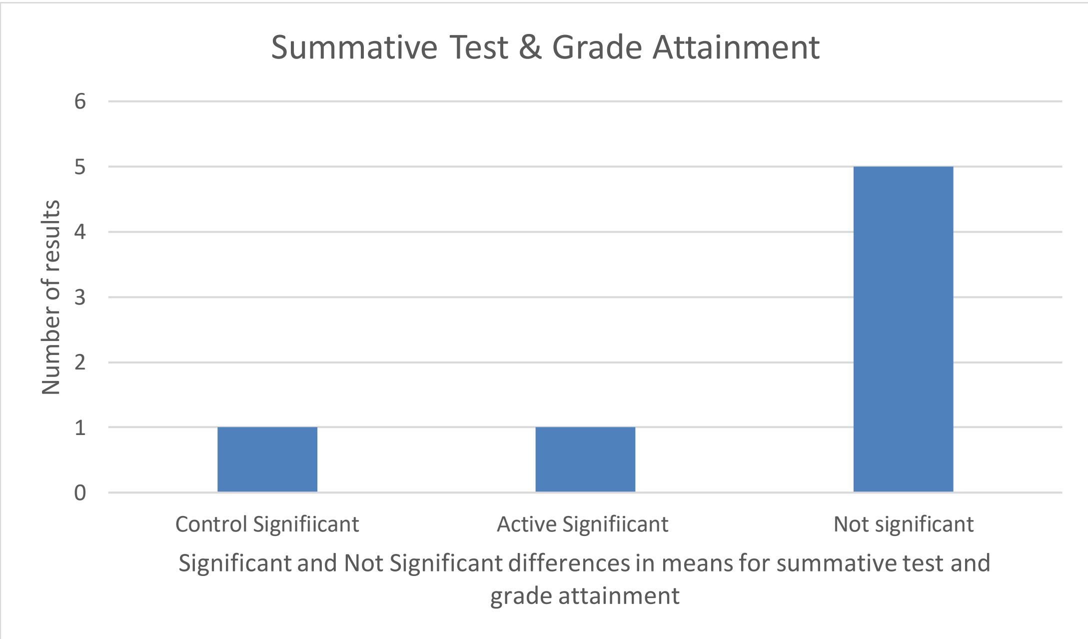


Figure 23 A bar chart of the numbers of non-significant differences in means, and significantly different means (higher for active or the control groups) for Science investigative skills attainment when independent t-tests were conducted

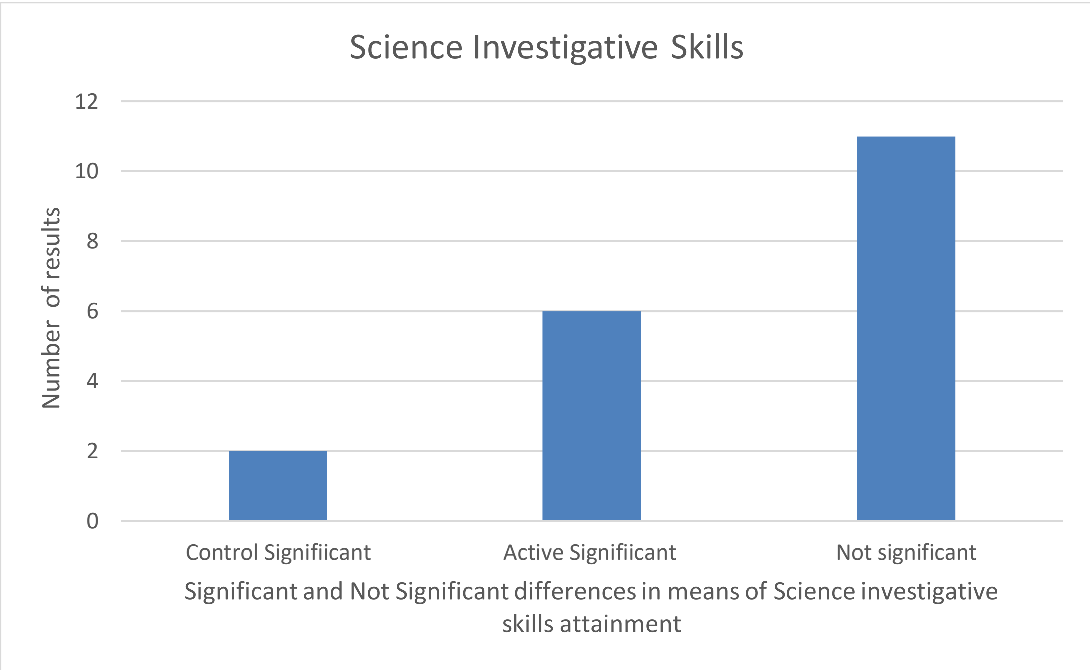
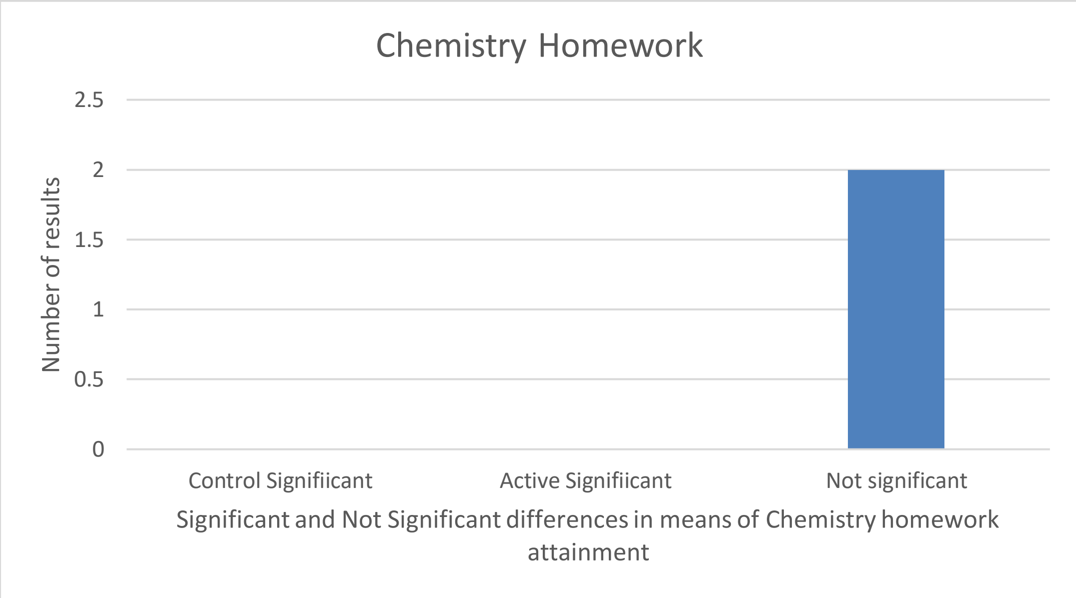


Figure 24 A bar chart of the numbers of non-significant differences in means, and significantly different means (higher for active or the control groups) for Chemistry homework attainment when

independent t-tests were conducted



4.1.5 An Introduction to Correlations between Post-test Working Memory Assessments and Science Assessment Attainment in both the control and active conditions in order to answer RQ b.

Inferential statistics were undertaken. Correlation analysis were carried out using statistics software IBM SPSS Version 26. Correlation analysis was conducted in order to test the strength of the relationship between post-test WM assessment and Science assessment attainment. Correlation analysis was conducted for both the active groups' and the control groups' post-test WM assessment and Science assessment attainment.

The correlations between the post-test WM assessments and the Science Assessment Attainment were conducted in order to provide data analysis evidence to answer RQ b. The r value was checked against that of the pre-test WM assessment correlations with the Science Assessment Attainment data. The correlations for the post-test data were only deemed to be significant if the pre-test correlations were not significant and the post-test correlations were significant; or the post-test correlations r value was greater than that of the pre-test correlation r value (highlighted in yellow in Tables 107 -121 p.518-556 Appendix H).

4.1.6 Correlation tests between Post-test Working Memory Assessments and Science Assessment of Investigative skills, Biology and Physics Attainment in both the control and active conditions in order to answer RQ b.

There were many non-significant correlations between WM and Science investigative skills attainment and between WM and homework attainment (Tables 107 -121 p.518-556 Appendix H). Where there was a significant correlation for the active group there was a corresponding significant correlation within the same assessment type for the control group (Figures 27 & 29, p. 236 & 238) . This means that any conclusion drawn from the small number of significant correlations will need to be tentative, and interpretation of those findings treated with caution (Chapter 5).

Figure 25 A bar chart of the large number of insignificant correlations between WM and Biology and Physics Homework attainment in both the active and control group

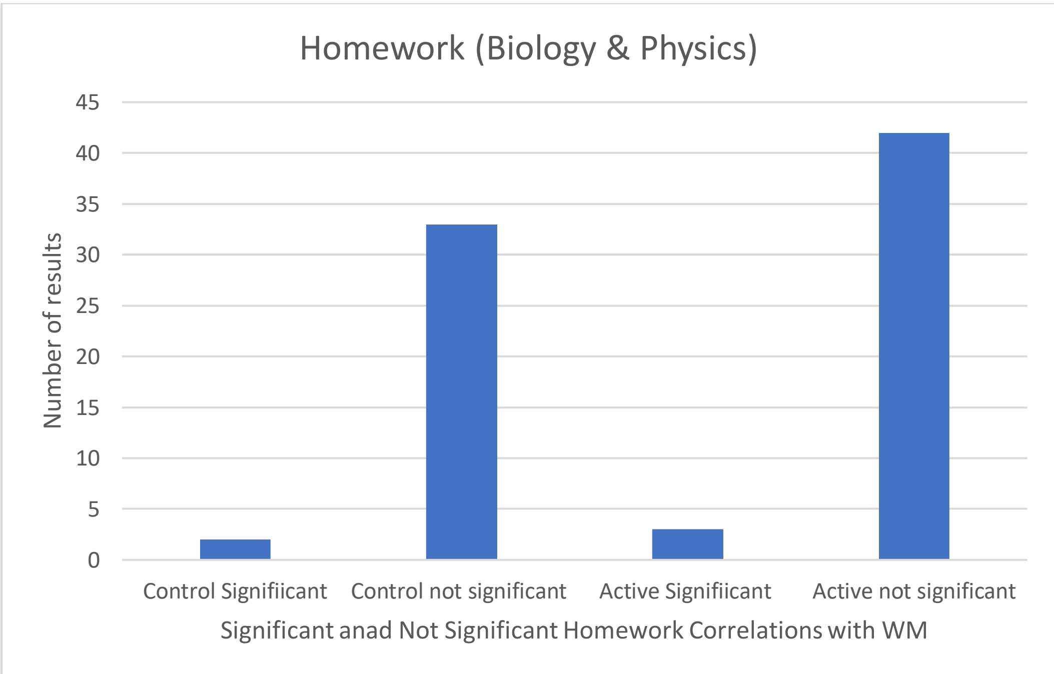
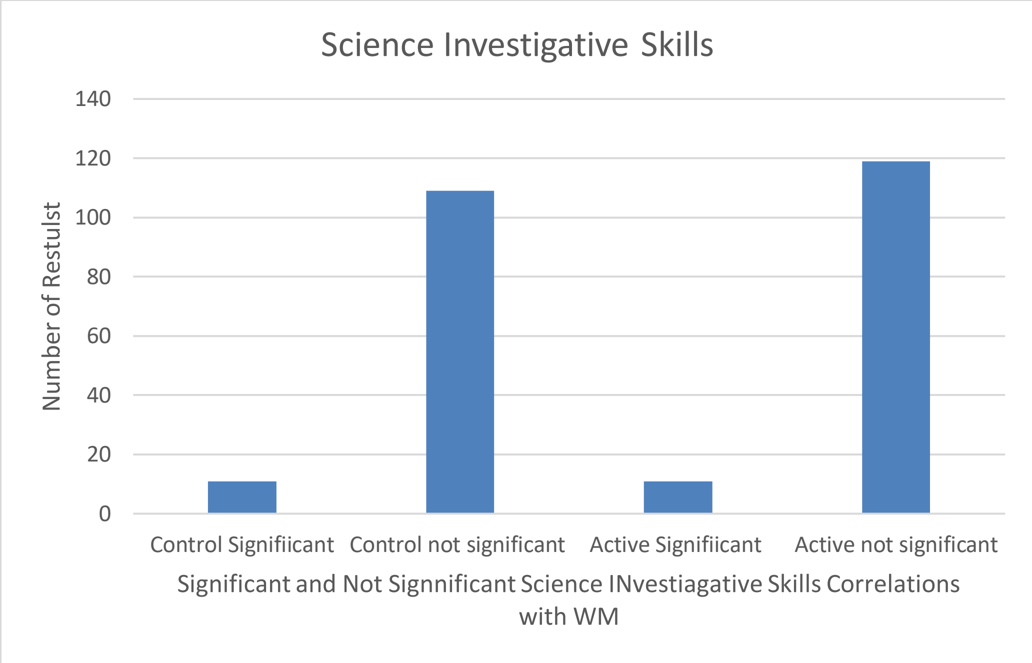


Figure 26 A bar chart of the large number of insignificant correlations between WM and Science investigative skills attainment in both the active and control group



4.1.7 Correlation tests between Post-test Working Memory Assessments and Science Assessment of Summative Tests & End of Year Grade Attainment in both the control and active conditions in order to answer RQ b.

Table 13 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Year 7 Summative Science Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Summative Science Assessment Attainment	Df	r	p	WM assessment measure	Summative Science Assessment Attainment	Df	r	p
Word Recall	Y7 Test 1	51	0.134	.337	Word Recall	Y7 Test 1	79	0.206	.065
Pattern Recall	Y7 Test 1	51	-0.043	.759	Pattern Recall	Y7 Test 1	79	0.306	.005(≤.05)
Counting Recall	Y7 Test 1	51	0.157	.260	Counting Recall	Y7 Test 1	79	0.205	.066
Working Memory Composite	Y7 Test 1	51	0.121	.388	Working Memory Composite	Y7 Test 1	79	0.312	.005(≤.05)
Working Memory Processing	Y7 Test 1	51	0.225	.109	Working Memory Processing	Y7 Test 1	79	0.210	.061
Word Recall	Y7 Test 2	79	.402	.000(≤.001)	Word Recall	Y7 Test 2	52	0.237	.085
Pattern Recall	Y7 Test 2	79	0.351	.001(≤.001)	Pattern Recall	Y7 Test 2	52	0.237	.084
Counting Recall	Y7 Test 2	79	0.254	.022(≤.05)	Counting Recall	Y7 Test 2	52	0.316	.020(≤.05)
Working Memory Composite	Y7 Test 2	79	0.409	.000(≤.001)	Working Memory Composite	Y7 Test 2	52	0.365	.007(≤.05)

Working Memory Processing	Y7 Test 2	79	0.046	.685	Working Memory Processing	Y7 Test 2	52	0.047	.739
Word Recall	Y7 Test 3	44	0.214	.154	Word Recall	Y7 Test 3	80	0.144	.197
Pattern Recall	Y7 Test 3	44	0.124	.411	Pattern Recall	Y7 Test 3	80	0.296	.007(≤.05)
Counting Recall	Y7 Test 3	44	0.261	.080	Counting Recall	Y7 Test 3	80	0.175	.115
Working Memory Composite	Y7 Test 3	44	0.302	.042(≤.05)	Working Memory Composite	Y7 Test 3	80	0.270	.014
Working Memory Processing	Y7 Test 3	44	0.089	.561	Working Memory Processing	Y7 Test 3	80	0.000	.999
Word Recall	End of Y7 Test	49	0.355	.011(≤.05)	Word Recall	End of Y7 Test	75	0.252	.027(≤.05)
Pattern Recall	End of Y7 Test	49	0.328	.019(≤.05)	Pattern Recall	End of Y7 Test	75	0.353	.002(≤.05)
Counting Recall	End of Y7 Test	49	0.309	.027(≤.05)	Counting Recall	End of Y7 Test	75	0.255	.025(≤.05)
Working Memory Composite	End of Y7 Test	49	0.415	.002(≤.05)	Working Memory Composite	End of Y7 Test	75	0.378	.001(≤.05)
Working Memory Processing	End of Y7 Test	49	-0.046	.749	Working Memory Processing	End of Y7 Test	75	0.126	.277
Word Recall	End of Y7 Report Grade	80	0.178	.109	Word Recall	End of Y7 Report Grade	80	0.312	.004(≤.05)
Pattern Recall	End of Y7 Report Grade	80	0.111	.321	Pattern Recall	End of Y7 Report Grade	80	0.265	.016(≤.05)
Counting Recall	End of Y7 Report Grade	80	0.067	.550	Counting Recall	End of Y7 Report Grade	80	0.149	.180
Working Memory Composite	End of Y7 Report Grade	80	0.158	.157	Working Memory Composite	End of Y7 Report Grade	80	0.317	.004(≤.05)
Working Memory Processing	End of Y7 Report Grade	80	-0.028	.807	Working Memory Processing	End of Y7 Report Grade	80	0.050	.656

There were some significant correlations identified between WM assessment and summative Science assessment for the active group; that were not present for the control group. Pattern Recall and Y7 Test 1 were correlated r(79)=.306, p=.005(P≤.05); Pattern Recall and Y7 Test 3 were correlated r(80)=.296 p=0.07(P≤.05); Pattern Recall and End of Y7 report grade were correlated r(80)=.265 p=0.016(P≤.05). Word Recall and End of Y7 report grade were correlated r(80)=.312, p=004(P≤.05) and WM composite and End of Y7 report grade were correlated r(80)=.317, p=.004 (P≤.05). Three of the five WM assessments were correlated to End of Y7 report grade attainment.

The majority of the WM assessments to Y7 Summative Science Assessment Attainment were found not to be correlated for the active group (Table 13). For example, WM word recall and Y7 test 1 were not correlated r(79)=.206, p=0.065 and WM Processing Speed and End of Y7 report grade were not correlated r(80)=.050, p=0.656. Also, a significant correlation in the control group between

Word Recall and Y7 Test 2 were correlated r(79)=.402 p=0.00P≤.001) was found. Any conclusions drawn from the statistically significant correlations between the active groups' WM assessment and the active groups' Science summative assessments will have to be tentative and treated cautiously. This is due to the large number of non-significant correlations between the active groups' WM assessment and the active groups' Science assessments.

A regression line analysis was conducted on the active groups' positive correlations between WM assessments and the summative assessment End of Year 7 Grade. The regression analysis was undertaken to quantify the strength of the relationship between WM assessment and End of Year 7 report grade.

Table 14a shows the regression analysis of the Post-test WM assessment and End of Year 7 report attainment with summative value of 0.234. This indicates that the WM of the active group students may be contributing to the End of year 7 report attainment by 23.4%. The same regression analysis was undertaken for the control group with the control group (Table 14 b). The WM of the control group may be contributing 3.3% to the End of year 7 report grade.

Table 14 a and b The regression analysis for the Post-test WM assessments with the End of year 7 Report attainment

Active Group		**P-value**	**Regression line analysis R^2**
Word Recall	End of year 7 Report	.004	0.086
Pattern Recall		.016	0.059
Counting Recall		Not significant	
Working Memory Composite		.004	0.089
Working Memory Processing		Not significant	
Total Regression line analysis R^2			0.234

Control Group		**P-value**	**Regression line analysis R^2**
Word Recall	End of year 7 Report	.109 Not significant	0.020
Pattern Recall		.321 Not significant	0.000
Counting Recall		.550 Not significant	
Working Memory Composite		.157 Not significant	0.013

Working Memory Processing		.807 Not significant	
Total Regression line analysis R^2			0.033

Table 15 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Year 8 Summative Science Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Summative Science Assessment Attainment	Df	r	p	WM assessment measure	Summative Science Assessment Attainment	Df	r	p
Word Recall	Y8 Test 1	79	0.305	.006(≤.05)	Word Recall	Y8 Test 1	75	-0.058	.615
Pattern Recall	Y8 Test 1	79	0.183	.102	Pattern Recall	Y8 Test 1	75	0.095	.413
Counting Recall	Y8 Test 1	79	0.330	.003(≤.05)	Counting Recall	Y8 Test 1	75	0.173	.133
Working Memory Composite	Y8 Test 1	79	0.354	.001(≤.001)	Working Memory Composite	Y8 Test 1	75	0.104	.370
Working Memory Processing	Y8 Test 1	79	0.082	.468	Working Memory Processing	Y8 Test 1	75	-0.092	.431
Word Recall	Y8 Test 2	79	0.126	.264	Word Recall	Y8 Test 2	74	-0.027	.817
Pattern Recall	Y8 Test 2	79	0.002	.989	Pattern Recall	Y8 Test 2	74	0.150	.194
Counting Recall	Y8 Test 2	79	0.036	.752	Counting Recall	Y8 Test 2	74	0.181	.118
Working Memory Composite	Y8 Test 2	79	0.080	.476	Working Memory Composite	Y8 Test 2	74	0.144	.214
Working Memory Processing	Y8 Test 2	79	- 0.035	0.760	Working Memory Processing	Y8 Test 2	74	-0.012	.921
Word Recall	End of Y8 Report Grade	78	0.332	.003(≤.05)	Word Recall	End of Y8 Report Grade	78	0.075	.508
Pattern Recall	End of Y8 Report Grade	78	0.247	.027(≤.05)	Pattern Recall	End of Y8 Report Grade	78	0.259	.020(≤.05)
Counting Recall	End of Y8 Report Grade	78	0.294	.008(≤.05)	Counting Recall	End of Y8 Report Grade	78	0.320	.004(≤.05)
Working Memory Composite	End of Y8 Report Grade	78	0.365	.001(≤.001)	Working Memory Composite	End of Y8 Report Grade	78	0.314	.005(≤.05)
Working Memory Processing	End of Y8 Report Grade	78	0.004	.974	Working Memory Processing	End of Y8 Report Grade	78	0.397	0.214

Pattern Recall and End of Y8 report grade were correlated r(78)=.259, p=020(P≤.05); WM composite and End of Y8 report grade were correlated r(78)=.314, p=.005 (P≤.05). Three of the five WM assessments were correlated to End of Y8 report grade attainment. The majority of the WM assessments to Y8 Summative Science Assessment Attainment were found not to be correlated for the active group (Table 15). For example, WM word recall and Y8 test 1 were not correlated r(75)=-.058, p=0.615 and WM Processing Speed and End of Y8 report grade were not correlated r(78)=.397, p=0.214.

A regression line analysis was conducted on the active groups' positive correlations between WM assessments and the summative assessment End of Year 8 Grade. The regression analysis was undertaken to quantify the strength of the relationship between WM assessment and End of Year 8 report grade.

Table 16a shows the regression analysis of the Post-test WM assessment and End of Year 8 report attainment with summative value of 0.269. This indicates that the WM of the active group students may be contributing to the End of year 7 report attainment by 26.9%. The same regression analysis was undertaken for the control group with the control group (Table 16 b). The WM of the control group may be contributing 24.7% to the End of year 8 report grade.

However, the majority of Year 8 students were being educated at home with no virtual lessons and no face-to-face contact. Work was being set each week and being marked and feedback given by the Year 8 teachers. There was large variability in how much engagement students had with this online work. Hence the End of Year 8 Report Grade might not be representative of the student's ability had school's not been shut due to the Covid-19 Pandemic.

Table 16 a and b The regression line analysis of Post-test WM assessments and Year 8 Science Attainment Grades

Active Group		**P-value**	**Regression line analysis R^2**
Word Recall	End of year 8 Report	Not significant	Not Significant
Pattern Recall		0.020	0.067
Counting Recall		0.004	0.103
Working Memory Composite		0.005	0.099
Working Memory Processing		Not significant	Not Significant
Total Regression line analysis R^2			0.269

Control Group		**P-value**	**Regression line analysis R^2**
Word Recall	End of year 8 Report	.003(≤.05)	N/A
Pattern Recall		.027(≤.05)	0.049
Counting Recall		.008(≤.05)	0.074
Working Memory Composite		.001(≤.001)	0.122
Working Memory Processing		.974	N/A
Total Regression line analysis R^2			0.245

In summary, the findings from the correlation tests undertaken to answer RQ b. do indicate that the active group students have some conceptual links (a correlation) in cognition between WM and students' knowledge & understanding of Science demonstrated in summative tests and end of Year report grades. These conceptual links (a correlation) in cognition between WM and students' knowledge and understanding of Science is present more in Year 7 students. . Given there are also many significant correlations this is a tentative conclusion that should be treated with caution.

4.1.8 Correlation tests between Post-test Working Memory Assessments and Science Assessment of Chemistry Homework Attainment in both the control and active conditions in order to answer RQ b.

Table 17 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Chemistry Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Chemistry 1a	49	0.092	.521	Word Recall	Chemistry 1a	52	0.277	.043(≤.05)
Pattern Recall	Chemistry 1a	49	0.074	.607	Pattern Recall	Chemistry 1a	52	0.209	.130
Counting Recall	Chemistry 1a	49	-0.191	.180	Counting Recall	Chemistry 1a	52	0.196	.155
Working Memory Composite	Chemistry 1a	49	-0.057	.693	Working Memory Composite	Chemistry 1a	52	0.306	.025(≤.05)
Working Memory Processing	Chemistry 1a	49	0.010	.947	Working Memory Processing	Chemistry 1a	52	0.144	.305
Word Recall	Chemistry 1b	49	0.266	.059	Word Recall	Chemistry 1b	52	0.067	.629
Pattern Recall	Chemistry 1b	49	0.121	.397	Pattern Recall	Chemistry 1b	52	0.083	.550
Counting Recall	Chemistry 1b	49	-0.022	.877	Counting Recall	Chemistry 1b	52	0.102	.461

Working Memory Composite	Chemistry 1b	49	0.118	.410	Working Memory Composite	Chemistry 1b	52	0.105	.450
Working Memory Processing	Chemistry 1b	49	0.133	.358	Working Memory Processing	Chemistry 1b	52	0.149	.287
Word Recall	Chemistry 2a	21	0.289	.181	Word Recall	Chemistry 2a	47	0.288	.045
Pattern Recall	Chemistry 2a	21	0.297	.169	Pattern Recall	Chemistry 2a	47	0.116	.426
Counting Recall	Chemistry 2a	21	0.372	.080	Counting Recall	Chemistry 2a	47	0.331	.020(≤.05)
Working Memory Composite	Chemistry 2a	21	0.341	.112	Working Memory Composite	Chemistry 2a	47	0.378	.007(≤.05)
Working Memory Processing	Chemistry 2a	21	0.126	.577	Working Memory Processing	Chemistry 2a	47	0.174	.233
Word Recall	Chemistry 2b	21	0.184	.401	Word Recall	Chemistry 2b	49	0.304	.030(≤.05)
Pattern Recall	Chemistry 2b	21	0.210	.335	Pattern Recall	Chemistry 2b	49	0.174	.223
Counting Recall	Chemistry 2b	21	0.329	.126	Counting Recall	Chemistry 2b	49	0.333	.017
Working Memory Composite	Chemistry 2b	21	0.257	.236	Working Memory Composite	Chemistry 2b	49	0.409	.003(≤.05)
Working Memory Processing	Chemistry 2b	21	0.267	.230	Working Memory Processing	Chemistry 2b	49	0.168	.239

There are some significant correlations between WM assessment and Chemistry Home Work for the active group that are absent in the control group (Table 17 p.208) For example WM composite and Chemistry Home Work 2a were correlated r(47)=-.378, p=.007(≤.05) and WM word composite and Chemistry Home Work 2b were correlated r(49)=-.409, p=.003(≤.05).

On the other hand, some of the WM assessments to Chemistry Home Work Science Assessment Attainment were found not to be correlated for the active group (Table 17 p.208). For example, WM word recall and Chemistry Home Work 1b were not correlated r(52)=-.067, p=.629 and WM Processing Speed and Chemistry Home Work 2b were not correlated r(49)=.168, p=0.239.

Overall, the findings from the correlation tests undertaken to answer RQ b. do indicate that the active group students have some conceptual links (a correlation) in cognition between WM and students' knowledge & understanding of Science demonstrated in chemistry homework. Given there are also many significant correlations this is a tentative conclusion that should be treated with caution.

4.1.9 An overall conclusion drawing from the Correlation tests between Post-test Working Memory Assessments and Science Assessment Attainment in both the control and active conditions in order to answer RQ b.

In summary, the findings from the correlation tests undertaken to answer RQ b. do indicate that the active group students have some conceptual links (a correlation) in cognition between WM and students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and students' knowledge and understanding of Science are present more in Year 7 active group students. This finding is supported by the regression analysis that suggests that WM is contributing to the end of Year 7 report grade by 23.4%. Given there are many non-significant differences between the means of the active and control group's Science attainment data. In addition to the large number of non-significant correlations between the active group WM assessment and Science attainment; this is a tentative conclusion that should be treated with caution.

4.2 Comparing the means of the Science Attainment Assessments using dependent (paired) t-tests in order to answer RQ b.

4.2.1 Introduction to the analysis of the dependent (paired) t-test for the pre-test and post-test Science attainment assessments in order to answer RQ b.

The lack of significant data for the unpaired t-tests comparing the means of the control and active group for the WM assessment measures and Science Attainment measures; alongside the correlation analysis not identifying many strong patterns of relationships between WM assessment and science attainment assessment led me to do further statistical analysis of the data.

Inferential statistics were undertaken, using the dependent (paired) t-test to analyse if there was a statistically significant difference between the means of the pre-test and post-test control group Science attainment assessments. Also, if there was a statistically significant difference between the means of the pre-test and post-test active group Science attainment assessments . This allowed me to see to gather inferential statistical findings to answer RQ b. The outcomes of the dependent (paired) t-test can be seen in Tables 122-137 p. 558-580 Appendix H.

Paired t-tests were undertaken for the active and control group. The pre-test and post-test WM assessment and Science attainment were statistically analysed and then the differences between the control and the active group compared. If the dependent t-test differences between the pre-test and post-test were more significant for the active group than the control group this has been commented on. If the dependent t-test differences between the pre-test and post-test were more significant for the control group than the active group this has also been commented on. This may give a weak indication that the active or control conditions might be having a small impact on changes in cognition. Any conclusions drawn from this analysis would have to be tentative, as the independent t-test differences in the means between the control and active group were not significant for Science assessment attainment. Furthermore, there were a large number of non-significant correlations between WM and Science assessment attainment for the active group.

4.2.2 Analysis of the dependent (paired) t-test for the pre-test and post-test Science attainment assessments in order to answer RQ b.

The key findings for the dependent (paired) t-test for the pre-test and post-test summative tests and end of year grade attainment for the control group and the active group is summarised in Table 18. (Appendix H Tables 124 & 125 p. 561 & 563) have the dependent t-test results in full). The more significant p-value is indicated are highlighted yellow in the table.

Table 18 The key findings for the dependent (paired) t-test for the pre-test and post-test summative tests and end of year grade attainment for the control group and active group.

Assessment Type	Control More Significant	Active More Significant	Not significant or the same
Post-test Y7 Test 2	.018 (≤.05) Yes	No	No
Post-test Y7 Test 3	No	.006(p≤.05) Yes	No
Post-test Y7 End of Year Test	No	No	Yes
Post-test Y7 End of Year Report grade	No	.000(p≤.001) Yes	No
Post-test Y8 Test 1	No	No	Yes
Post-test Y8 Test 2	No	No	Yes
Post-test Y8 End of Year Report Grade	No	No	Yes

A large number of non-significant findings can be found in Table 18 (not highlighted in yellow). This needs to be taken into consideration when drawing conclusions from the significant findings. Caution is needed when interpreting this data.

The control group results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y7 Test 2 (M=7.4685, SD=0.09486) Science Summative assessment weakly indicate that having traditional teaching methods in their Science lessons may have a positive impact on the cognition of their knowledge and understanding in Science, t(58)=-2.442, p=.018

On the other hand, the active group results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y7 Test 3 (M=7.4156, SD=0.08060) Science Summative assessment may weakly indicate that completing WM activities in their Science lessons may have a positive impact on the cognition of their knowledge and understanding in Science, t(55)=-2.879, p=.006

Furthermore, the active group results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative End of Y7 Report Grade (M=7.4522, SD=0.12084) Science Summative assessment may weakly indicate that completing WM activities in their Science lessons may have a positive impact on the cognition of their knowledge and understanding in Science, t(85)=-4.346, p=.000.

In summary, the data tentatively indicates that the activities to develop WM may have may have a positive impact on the cognition of their knowledge and understanding in Science demonstrated in one summative test and the end of Y7 Report Grade. In the light of the number of non-significant findings throughout the analysis this conclusion should be treated extremely cautiously.

The key findings for the dependent (paired) t-test for the pre-test and post-test for the Science Investigative Skills assessment attainment for the control group and the active group is summarised in Table 19. (Appendix H Tables 126 & 133, p.565 & 577) have the dependent t-test results in full). The more significant p-values are indicated are highlighted yellow in the table.

Table 19 The key findings for the dependent (paired) t-test for the pre-test and post-test Science Investigation Skills Assessments

Assessment Type	Control More Significant	Active More Significant	Not significant or the same
Planning Assessments	.001(p≤.001) Yes	No	No
	.001(p≤.001) Yes	No	No
	No	No	Same
	No	No	Active group is significant but no comparative data
Obtaining Evidence Assessments	Completely different means Yes	No	No
	Completely different means Yes	No	No
	No	No	Yes
	.000(p≤.001) Yes	No	No
	No	.038(p≤.05) Yes	No
	No	No	Yes
	No	No	Yes
Analysis Assessments	No	No	Yes
	.000(p≤.001) Yes	No	No
	No	No	Yes
	No	.000(p≤.001) Yes	No
	.000(p≤.001) Yes	No	No
	No	No	Active significant but no comparable data
Evaluating Assessments	.021(p≤.05) Yes	No	No
	.001(p≤.001) Yes	No	No
	No	No	Control significant but no comparable data
	No	No	Yes
	0.020(p≤.05) Yes	No	No

A large number of non-significant findings can be found in Table 19 (not highlighted in yellow). This needs to be taken into considerations when drawing conclusions from the significant findings. Caution is needed when interpreting this data.

The significant findings for the control group results from the pre-test Planning (M=7.3107, SD=0.10415) and post-test Electromagnet Planning (M=7.5207, SD=0.09403) Science skills assessment indicate that having traditional teaching methods in their Science lessons may have a positive impact on the cognition of their skills & knowledge in the Science investigative skill of planning, t(26)=-13.301, p=.000. In addition, the control group results from the pre-test Planning (M=7.3107, SD=0.10415) and post-test Yeast Planning (M=7.5103, SD=0.13455) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their skills & knowledge in the Science investigative skill of planning, t(26)=-6.802, p=.000

The active group results did not have any results that were more significant than the control group for the Planning Science skills assessment.

The control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the control have a more significant difference (when looking at the t-values) than that of the active group for the Planning in the Electromagnet, Yeast, and Sound Investigations. This is a small tentative indicator that the WM activities may have little or no impact on the cognition of the active group students' Science investigative skills of planning. Alternatively, the normal way of teaching , may have a positive impact on the cognition of the control group's Science investigative skill of planning.

The significant findings for the control group results for the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Electromagnets (M=7.507, SD=0.088) and Rock Salt Obtaining Evidence (M=7.507, SD=0.087) showed that they had completely different means and so a dependent t-test was not necessary. Furthermore, the control group results from the pre-test

Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Spring Obtaining Evidence (M=7.5808, SD=0.09389) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Obtaining Evidence, t(24)=-12.626, p=.000

On the other hand, the active group results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Yeast Obtaining Evidence (M=7.6667, SD=0.05774) Science skills assessment may weakly indicate that having activities to develop WM in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Obtaining Evidence, t(2)=-5.000, p=.038.

Overall, the control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the control have a more significant difference (when looking at the t-values) than that of the active group for the Obtaining Evidence assessments. This is tentatively indicating, that the WM activities may have little or no an impact on the cognition of their Science investigative skill of Obtaining Evidence. Whereas, the findings may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of the control group's Science investigative skill of Obtaining Evidence.

The significant key findings are for the control group results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Spring Analysis (M=7.4304, SD=0.11455) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Analysis, t(21)=-5.923, p=.000. Furthermore, the control group results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Seed Dispersal Analysis (M=7.5512, SD=0.14076) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their Science investigative skill Analysis Science skills, t(74)=-9.436, p=.000.

The active group results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Pendulum Analysis (M=7.5390, SD=0.18364) Science skills may weakly indicate that having activities to develop WM in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Analysis, t(73)=-4.718, p=.000

The control and the active group's dependent t-tests on the Analysis Science Investigative Skills pre-test and post-test assessment indicate that they are not significantly different to each other (see independent t-test section) the control group has slightly more of a significant difference (when looking at the t-values). This outcome may weakly indicate, that the activities to develop WM are not having a positive impact on the cognition of the active group's Science investigative skill of Analysis. Whereas, the data weakly suggests, that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of the control group's Science investigative skill of Analysis.

The control group results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Rock Salt Evaluating (M=7.3593, SD=0.11184) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Evaluating, t(26)=2.467, p=.0.021. Furthermore, the control group results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Spring Evaluating (M=7.3737, SD=0.12842) Science skills assessment may weakly indicate that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of their Science investigative skill of Evaluating, t(17)=-4.242, p=.0.001. None of the active group's Evaluating Science Skills assessments was more significant than the control groups.). This outcome may weakly indicate, that the activities to develop WM are not having a positive impact on the cognition of the active group's Science investigative skill of Evaluating. Whereas, the data weakly suggests, that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of the control group's Science investigative skill of Evaluation.

To summarise, the control group had 8 more significant findings compared to the active group for the Science Investigative Skills dependent t-tests comparative data (Table 19). This very tentatively suggests, that the activities to develop WM are not having a positive impact on the cognition of the active group's Science investigative skills. Whereas, the data weakly suggests, that having traditional teaching methods in their Science lessons, may have a positive impact on the cognition of the control group students Science investigative skills. This is discussed in Section 5.3.

Table 20 The key findings for the dependent (paired) t-test for the pre-test and post-test for the Chemistry Homework Assessment

Assessment Type	Control More Significant	Active More Significant	Not significant or the same
Chemistry Homework	No	0.07(p≤.05) Yes	No
	.000(p≤.001) Yes	No	No

The active group's results from the pre-test (M=7.4175, SD=0.12265) and post-test (M=7.4836, SD=0.24173) for Chemistry homework a. may weakly indicate that completing WM activities in their Science lessons may have a positive impact on the cognition of their Science knowledge and understanding in Chemistry homework a, t(49)=-2.792, p=.007 that is greater than the significant improvement in the same homework for the control group.

On the other hand, the control group's results from the pre-test (M=7.4786, SD=0.17026) and post-test (M=7.5241, SD=0.24002) for Chemistry homework b may weakly indicate that having traditional teaching methods in their Science lessons may have a positive impact on the cognition of their Science knowledge and understanding in Chemistry b homework, t(27)=-3.742, p=.001. In summary, there is no overall evidence to indicate the activities to develop WM have may have a positive impact on the cognition of the active group students in their knowledge and understanding of Chemistry homework attainment. This means any conclusions drawn from other significant findings of the activities to develop WM having a positive impact on the cognition of the active group student's knowledge and understanding of Chemistry homework must be extremely tentative.

Non-significant findings can be found in Table 20 (not highlighted in yellow). This needs to be taken into considerations when drawing conclusions from the significant findings. Caution is needed when interpreting this data.

4.3 The Key Findings of the Analysis of the Perception Data (some qualitative): Lesson Observations, Student Interviews, Student and Staff Questionnaires in order to answer RQ a, c, d & e.

The perception data that was collected for this PhD thesis is listed below.

- Lesson observations (50 in Year 7 & 84 in Year 8)
- Student interviews during lesson observations
- Student questionnaires (twice a year)
- Science Teacher questionnaires (three times a year)
- Science lesson Teaching Assistant questionnaire (once a year)
- Whole staff questionnaire (once a year)

This section will predominantly analyse the perception data that directly contributes to answering the thesis questions (other data not linked directly to the key findings can be found in Appendices E, F and H):

What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?

a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, science and learning in Science compared to the control conditions?

e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

The analysis was conducted by examining the student interviews, student questionnaires and aspects of the lesson observation data. Descriptive statistics were used to quantify and analyse the difference between the active and control group responses. The use of frequencies or percentages were used for comparisons between the active and control conditions. The qualitative data gathered from Science Teacher Questionnaires, Science lesson Teaching Assistant Questionnaires, a Whole Staff Questionnaire and some aspects of the lesson observations and Student Questionnaire data is also considered either here in Section 4.3 or in Appendix H.

4.3.1 Analysis of Student Interviews

In the majority of the Year 7 lesson observations (48 out of 50) students (usually two) were interviewed about their experience of the Working Memory activities. In the control group 49 students were interviewed, in the active group 46 student were interviewed. The two lessons where there were no student interviews were due to a teacher demonstrating a practical that from a safety point of view it was imperative that all students listened to.

In Year 8 the active group classes were observed 47 times and the control group classes 37 times. A total of 84 lesson observations over the nearly two terms that the school was open before the pandemic started and the first partial school closure happened in March 2020.

The students were asked a number of questions in the order shown below:

(See Appendix G)

- Do you do the memory activities in your lessons?
- (If yes) Do you find the memory activities useful for your learning?
- Explain why
- Do you find science easy medium or difficult (researcher added in medium when students started to respond medium to early lesson observation interviews)?
- Explain why you find science easy medium difficult?
- What activities do you do in Science that help you learn the most?

The Year 7 question responses that could be quantified are shown in Table 21

Table 21 The Year 7 student quantifiable responses to interviews that took place in the lesson observations

Question	Response	Percentage of Responses %	
		Control	Active
Do you do memory activities in your lessons?	Yes	0	100
	No	100	0

(If Yes) Do you find memory activities useful for your learning?	A lot		28
	Yes		64
	A bit		2
	No		4
Do you find Science easy, medium, or difficult?	Easy	18	4
	Medium	82	84
	Difficult	0	8
	No Response	0	4
What activities do you do in Science that help you learn the most? (first activity students stated)	Practical work	44	38
	Reading Sheets	8	12
	WM listening activities	0	12
	All Activities	0	8
	Quiz	0	6
	Other * See Appendix	50	24

In Year 7 the vast majority of students in the active group did think that the memory activities were useful for their learning. The control group students were not asked the question as they had responded negatively to the previous question.

Table 21 p.221 shows the difference in response to the question ***"What activities do you do in Science that help you learn the most?*** The "other" responses were more varied from the control group including cut and stick, PowerPoints, and research whereas the majority of the active groups' responses included the WM activities. The active groups' "other" responses were more limited but did include "life examples" and "being creative."

The active group students responded in a more variable way to the question, ***"Explain why you find the memory activities useful for your learning?"***

The constant comparative method was used when analysing their responses, the words or phrases that were the most common are recorded in Table 22 p.224. (Many of the students mentioned more than one word or phrase). The responses support the positive way the students view the WM activities. The students had a diverse way of explaining why the Working Memory activities are useful for their learning. The frequency of the words; remember, focus and science equipment (apparatus) indicate that the students' learning may be enhanced by the Working Memory activities. However; two students stated that the memory activities were not useful for their learning; when asked why one student stated they couldn't see the link between the memory activities and their science learning. The other student stated that they thought the Working Memory activities were not linked to science. The possibility that WM activities might not have a positive effect on all students and any negative impact on student attainment will be discussed with reference to relevant literature in the discussion.

On the other hand, the positive responses from the students shown in Table 22 indicate that the WM activities may have an impact on the cognition of the active group students that leads to a differing metacognitive effect. The students' use of words such as remember, brain, think, focus, listen supports this observation of a possible positive link between the use of WM activities and metacognition. This metacognition supports the fact that students are thinking about how the activities are impacting on their learning.

However, some of the responses that are interesting in terms of this research are where two students have stated that doing the Working Memory activities in science are helping them learn in other lessons (subjects). So, in the case of two responses there has been an impact or effect seen in other subjects. This is called the far transfer effect in WM research and is it not commonly reported in findings in the literature. This tentatively suggests that students completing activities to develop

WM in Science may have a positive impact on the cognition of students in another subject they are studying.

Table 22 The range of responses the Year 7 students in the active group gave to the question "Explain why you find the memory activities useful for your learning?"

Active Student Common words in Responses to ***"Explain why you find the memory activities useful for your learning?"***	Number of times word was used in response
Remember	12
Memory	12
Focus	8
Science Equipment (Apparatus)	7
Useful	6
Listen	5
Learn	3
Other lessons (subjects)	2
More instructions in class	2
Brain	2
Do them at the start of lessons	2
Think	2
Practicals	1
Dyslexia	1
Fun	1
Homework	1

Table 23 The frequency of Year 7 responses to the question "Why do you find science easy/ medium/ difficult"

Response to question ***"Why do you find science easy/medium/difficult?"***	Control Group Frequency of response	Active Group Frequency of response
It is easy (details in Table 55 p. 432 of appendix E)	3	1
Sometimes Science is easy and sometimes science is hard	20	10
STUDENTS FIND SCIENCE CHALLENGING (details in Table 56 p.432 appendix E)	8	6

Other responses in complete Table 56 of Appendix E

The data in Table 23 p. 225 indicates that proportionally the students in the active group found Science slightly less challenging than the students in the control group. This may indicate that the WM activities are marginally shifting the active group students' cognition linked to learning Science. However, the difference is very small and the distributions are similar so this conclusion is very tentative without any other evidence to support this observation.

Table 24 The analysis of the Year 8 students' response in percentage to student interviews including what activity in Science helps them learn the most (including their first and second response)

Question	Response	Percentage of Responses %	
		Control	Active
Do you do memory activities in your lessons?	Yes	0.0	100.0
	No	100.0	0.0
	A lot	[redacted]	0.0

(If Yes) Do you find memory activities useful for your learning?	Yes	[redacted]	83.0
	A bit		12.8
	No		4.8
Do you find Science easy, medium, or difficult?	Easy	10.8	12.8
	Medium	86.5	66.0
	Difficult	2.7	12.8
	Depends	0.0	8.5
What activities do you do in Science that help you learn the most? (first activity students stated)	Practical work	51.4	29.8
	Demonstrations	2.7	10.6
	Listening Activities	0.0	10.6
	Reading Sheets	16.2	10.6
	Other* see Appendix E	18.9	19.2
What activities do you do in Science that help you learn the most? (second activity students stated)	Reading Sheets	2.7	8.5
	Practicals	10.8	0.0
	Other* see Appendix E		

Table 25 The range of responses the Year 8 students in the active group gave to the question "Explain why you find the memory activities useful for your learning?"

Active Student Common words in Responses to ***"Explain why you find the memory activities useful for your learning?"***	Number of times word was used in response
Remember	24
Memory	6
Reading Sheets	6
Other lessons	5
Listen(ing)	4
Learn	4
Science Equipment (Apparatus)	3
Science	3
Practicals	2
Focus(ed) Concentrate	2
Revision	2
More instructions in class	1
Brain	1
Do them at the start of lessons	1

Table 26 The Year 8 Student response to explaining why they find science easy medium or difficult.

Response to question ***"Why do you find science easy/medium/difficult?"***	Control Group Frequency of response	Active Group Frequency of response
It is easy	1	4
Sometimes Science is easy and sometimes science is hard	13	18
Students find Science difficult	3	6
Student stated that a specific Science area was more difficult/easy than another	6	6
The teacher explains Science well	2	0

I like Science	3	1
Challenging & good	1	2
Other	6	5

In Year 8, the vast majority of students in the active group did think that the memory activities were useful for their learning although the response is not quite as positive as it is in Year 7 (Tables 21 and 23, p. 221 & 225). The control group students were not asked the question as they had responded negatively to the previous question. The Year 8 active group students responded in a variable way to the question, ***"Explain why you find the memory activities useful for your learning?"***.

The constant comparative method was used when analysing their responses, the words or phrases that were the most common are recorded in Table 25 p. 227 (many of the students mentioned more than one word or phrase). The responses support the positive way the students view the activities to develop WM. The students had a diverse way of explaining why the Working Memory activities are useful for their learning. The frequency of the words; remember, memory, reading sheets, other lessons indicate that the students' learning may be enhanced by the Working Memory activities. There were five students that mentioned that the memory activities were helping them in other lessons. This evidence tentatively suggests the activities to develop WM may a far transfer effect.

However; two students stated that the memory activities were not useful for their learning; and two students said that it would be beneficial to have more time with the reading sheets. However, two other students specifically stated that it helped them at home and another student also stated that the activities helped them in real life. This is more tentative evidence indicating that there may be a far transfer effect of the activities to develop WM in home / day to day domestic life not just in school lessons.

On the other hand, the positive responses from the students shown in Table 25 p. 227 indicate that the WM activities may have a positive impact on active group student cognitions that may lead to a differing metacognitive effect. The students' use of words such as remember, memory, listen(ing), learn, focus(ed), concentrate and brain supports this observation of a possible positive link between the use of WM activities and metacognition. This data supporting the possible differing metacognition supports the fact that students are thinking about how the activities to develop WM are impacting on their learning.

The data in Table 26 p. 227 shows the student response to why students think Science is easy, medium, or difficult. The data indicates that proportionally the students in the active group found Science marginally more challenging (and good) and easier than the students in the control group. However, proportionally the control students stated they liked Science slightly more. This may indicate that the activities to develop WM may have an impact on the active group students' cognition and hence perspective on learning Science or could suggest that the activities to develop WM, may have an impact on cognition of the active group students. This might be having a polarising effect making Science easier or harder to learn depending on certain factors. However, as the distributions are very similar these are tentative conclusions and would need other evidence to support them from the qualitative and quantitative data from further research (Section 5.7.10)

4.3.2 Analysis of Student Questionnaire Responses

The students completed two questionnaires (Appendix G) in the first year of the study. The students were given the first questionnaire just after the start of the study. The students had at this point in the study completed the baseline Working Memory tests. The second questionnaire was completed in the second half of the summer term of the first academic year of the study. The Year 8 questionnaires were completed in the first half term and the third half term of the academic year (a third questionnaire would have been administered in the fifth half term but the partial closure of the school (due to the Covid 19 pandemic) to all but Key Worker students meant this was not possible).

The questionnaire asked a number of questions. Students could respond yes, a bit or no. There was also an opportunity for students to add a comment.

- I can remember information from lessons really well
- I think that having a good memory is important for learning
- I think having a good memory is part of being intelligent
- In science lessons I do activities to practice using my memory
- In other subjects I do activities to practice using my memory
- I use the memory skills I practice in Science in other subjects
- I am learning new information and skills in Science
- I have a good memory
- I am intelligent

4.3.3 Analysis of the comparison of the control group and active group student questionnaires

Table 27 The analysis of the active and control group questionnaires. The questionnaire responses were compared to the first questionnaire completed. The data is positive for the active group compared to the control group and if the difference suggests a particular conclusion to be drawn it is highlighted in green.

Questions	Qre 1 compared to Qre 2 Difference between the control and active responses %						Qre 1 compared to Qre 3 Difference between the control and active responses %						Qre 1 compared to Qre 4 Difference between the control and active responses %					
	Yes		A Bit		No		Yes		A Bit		No		Yes		A Bit		No	
Group Control = C Active = A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A
I can remember information from lessons really well	-2.6	5.7	5.8	-6.1	-3.2	0.5	+6.4	-3.5	+4.6	+2.4	-1.9	+1.1	+5.8	-3.0	+2.3	+1.5	-3.5	-1.5
I think that having a good memory is important for learning	-2.7	5.1	1.6	-3.9	1.2	- 1.2	-1.8	+1.2	+10.2	-1.1	0.0	0.0	- 16.2	-11.4	+16.2	+10.0	0.0	+0.1
I think having a good memory is part of being intelligent	- 14.7	4.7	- 26.7	- 12.3	41.4	5.4	- 12.7	+9.4	+6.2	-10.6	+6.5	+2.4	-1.4	+16.1	+8.0	-18.4	-6.6	-3.6
In science lessons I do activities to practice using my memory	4.5	1.8	-2.8	1.2	-1.7	-3	-6.8	+7.1	-1.6	-7.0	+8.4	0.0	-6.7	+0.6	-17.3	+4.0	+23.9	-4.6

In other subjects I do activities to practice using my memory	-1.3	-6.1	-6.2	1	6.2	5.1	-9.0	-15.3	-0.2	-17.6	+9.1	+32.9	-2.9	-14.3	-2.4	-20.5	+5.3	+34.9
I use the memory skills I practice in Science in other subjects	-3.6	-2.5	-3.1	-3.9	5.4	8.7	-7.7	-4.7	-0.8	-1.2	+8.4	+8.2	-5.2	-6.1	-6.3	-0.8	+10.1	+9.2
I am learning new information and skills in Science	6.1	-2.3	-7.3	3.5	2.4	-1.2	-1.6	-9.4	-0.4	+10.6	+1.2	0.0	-0.9	-10.2	-5.3	+10.1	+5.6	+0.1
I have a good memory	8.3	-0.6	-3.1	1.4	-5.2	0.4	+6.9	-1.2	-0.9	0.0	-6.0	+2.3	+0.6	-2.0	+0.3	-1.0	-1.1	+4.2
I am intelligent	0.1	0.4	-6.5	2.3	6.5	-1.5	-1.5	+3.3	+0.5	-8.2	+1.0	-5.9	-5.8	+2.4	+3.7	0.0	+2.2	-2.5

Figure 27 The responses of Questionnaire 1 compared to Questionnaire 2 Positive Perception of active group compared to control group for the "Yes" Responses

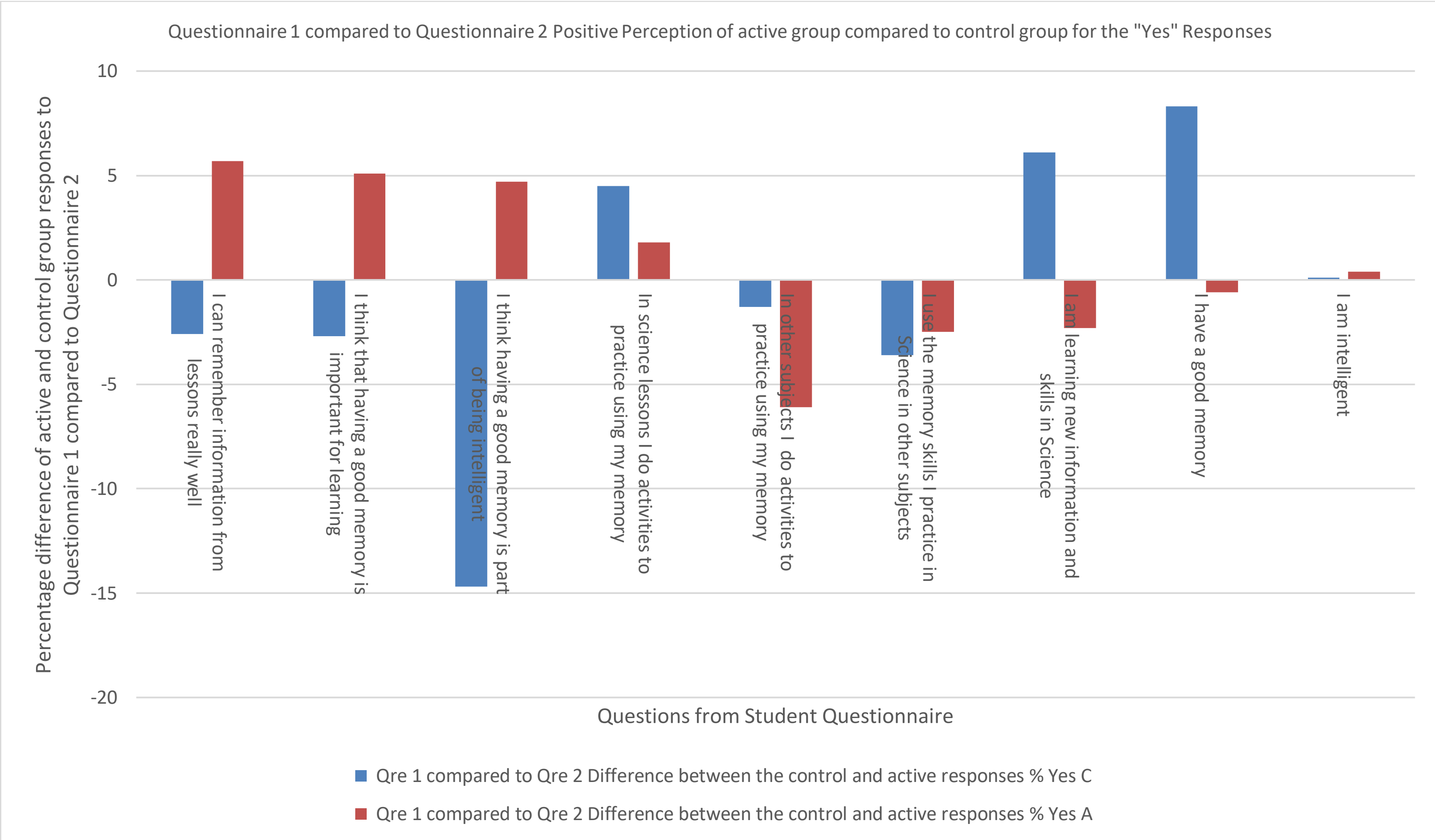


Figure 28 The responses of Questionnaire 3 compared to Questionnaire 4 Positive Perception of active group compared to control group for the "Yes" Responses

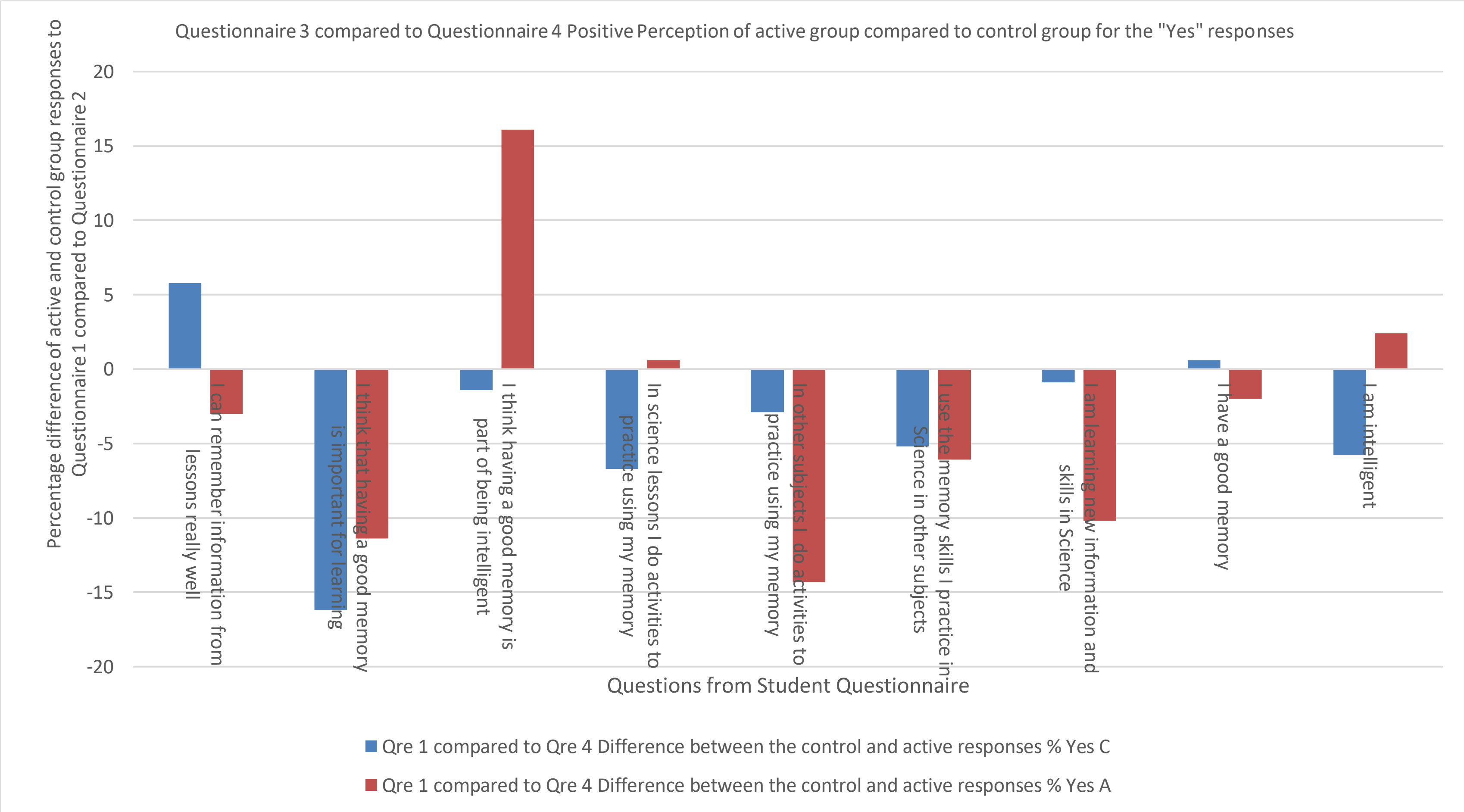
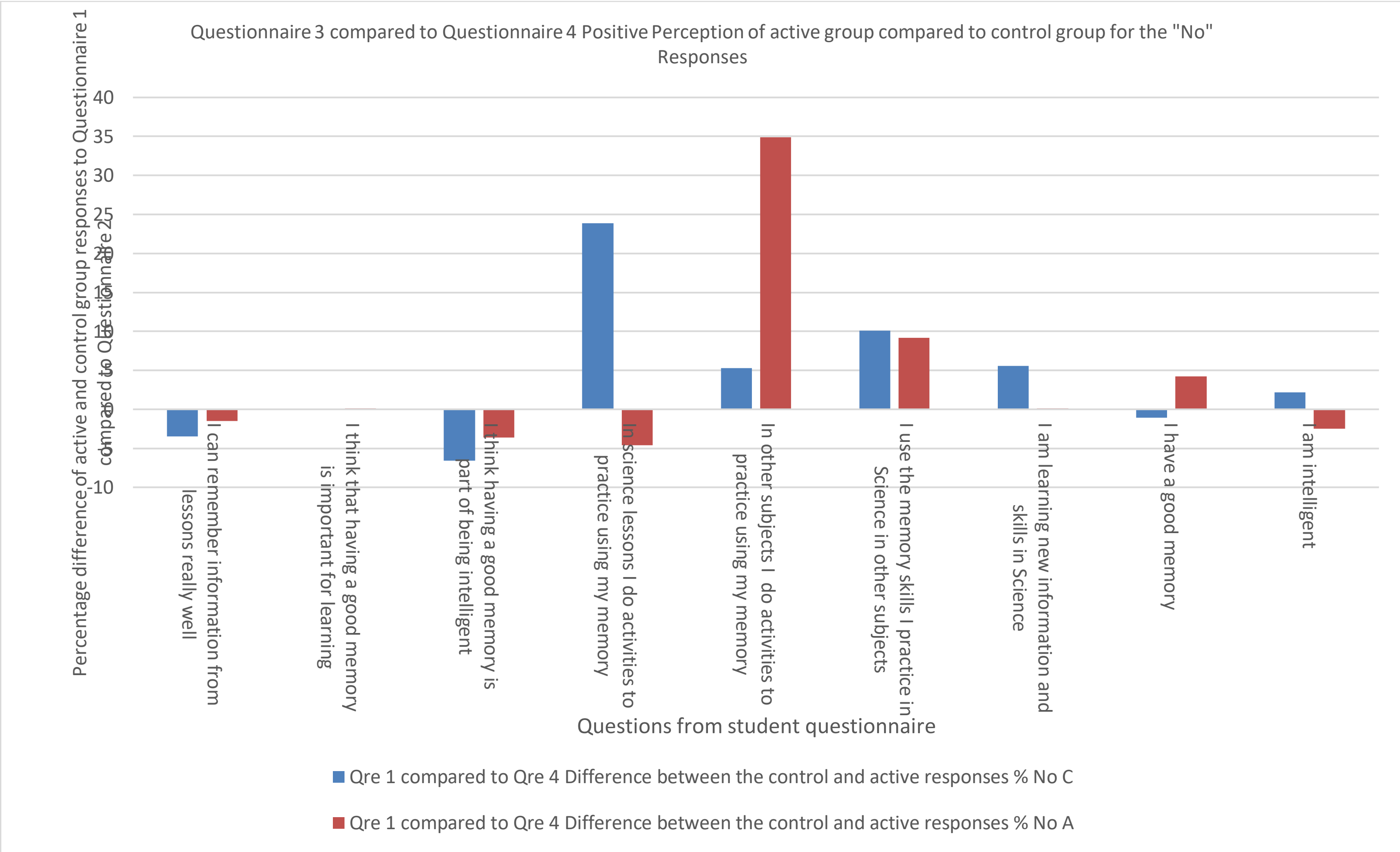


Figure 29 The responses of Questionnaire 3 compared to Questionnaire 4 Positive Perception of active group compared to control group for the "No" Responses



The analysis of comparing the questionnaires throughout the study is shown in Table 27 p. 230 and Figures 27-29. The responses to the student questionnaires given at different time points throughout the study; were compared to responses from the first student questionnaire. This would give an indication of student perception on memory, attainment and far transfer effects changing over the course of the study. In the response to the statement “I remember information from lessons really well” Year 7 response comparing questionnaires 1 and 2 suggests with an increase of 5.7% that WM activities may have impacted on perception of attainment. This same pattern can be seen in the Year 7 response to “I think that having a good memory is important for learning”, showing an active group increase of 5.3%. This can be seen clearly in Figure 27.

Figures 27-29 show that over the two years there is an increase in the positive response by the active group to “I think that having a good memory is part of being intelligent.” Questionnaire 2 compared to questionnaire 1 is an increase of 4.7% and the questionnaire 4 compared to questionnaire 1 is an increase of 16.1 %. This tentatively indicates that the activities to develop WM may have an impact on the active students’ cognition and hence their perception of memory. However, these results are not echoed in response to the statement “I have a good memory.” On the other hand, there is a similar pattern of increase when comparing the responses to the statement “I am intelligent” albeit with smaller percentage increases.

Active student perception of attainment is favourable towards the end of Year 8 compared to Questionnaire 1. The response to “I am learning new information and skills in science” had an increase 10.2 % (Figure 29). This tentatively suggests that WM activities may be having an impact on active students’ cognition that may lead to a more positive perception of attainment.

Table 28 The analysis of the active and control group questionnaires. The questionnaire responses between control and active responses were compared at each data collection point. The data is positive for the active group compared to the control group and if the difference suggests a particular conclusion to be drawn it is highlighted in green

Qs	Qre 1 compared to Qre 1 Difference between the control and active responses %			Qre 2 compared to Qre 2 Difference between the control and active responses %			Qre 3 compared to Qre 3 Difference between the control and active responses %			Qre 4 compared to Qre 4 Difference between the control and active responses %		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	6.8	-0.1	-6.7	15.1	-12	-3	-3.1	+6.9	-3.7	-2.0	+3.7	-1.7
I think that having a good memory is important for learning	0.8	-2	1.2	8.6	-7.5	-1.2	+3.8	-4.9	+1.2	+6.0	-8.2	+1.3
I think having a good memory is part of being intelligent	-20.6	18	1.4	-1.2	+32.4	-34.6	+1.5	+1.2	-2.7	-3.1	-8.4	+11.6
In science lessons I do activities to practice using my memory	42.1	-27.5	-14.6	39.4	-23.5	-15.9	+56.0	-33.0	-23.0	+49.4	-6.2	-43.1
In other subjects I do activities to practice using my memory	-6	6.7	-0.8	-10.8	13.9	-1.9	-12.3	-10.7	+23.0	-17.4	-11.4	+28.8
I use the memory skills I practice in Science in other subjects	-4.8	+8.7	-6.3	-3.7	+7.9	-3	-1.8	+8.3	-6.5	-5.7	+14.2	-7.2
I am learning new information and skills in Science	+16.7	-16.7	1.2	8.3	-5.9	-2.4	+8.9	-6.5	-1.2	+5.6	-1.3	-4.3
I have a good memory	-3.5	7.4	-5.2	-12.4	11.9	0.4	-11.6	+8.3	+3.1	-6.1	+6.1	+0.1
I am intelligent	-1.1	2.9	-3	-0.8	11.7	-11	+3.9	-5.8	+1.9	-2.0	+3.7	-1.7

Figure 30 The percentage difference in Questionnaire 1 "Yes" responses between the control & active groups

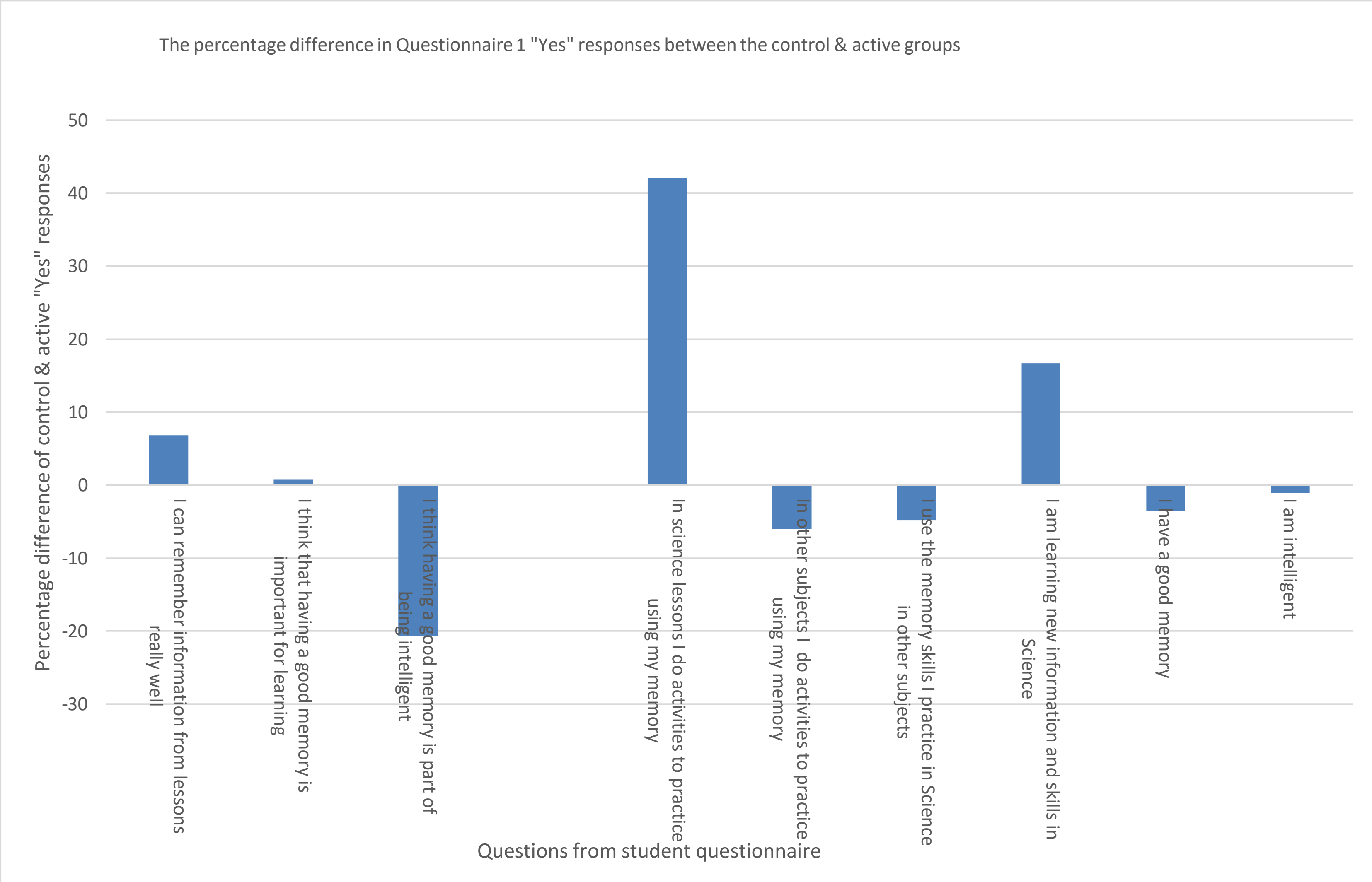


Figure 31 The percentage difference in Questionnaire 2 "Yes" responses between the control & active groups

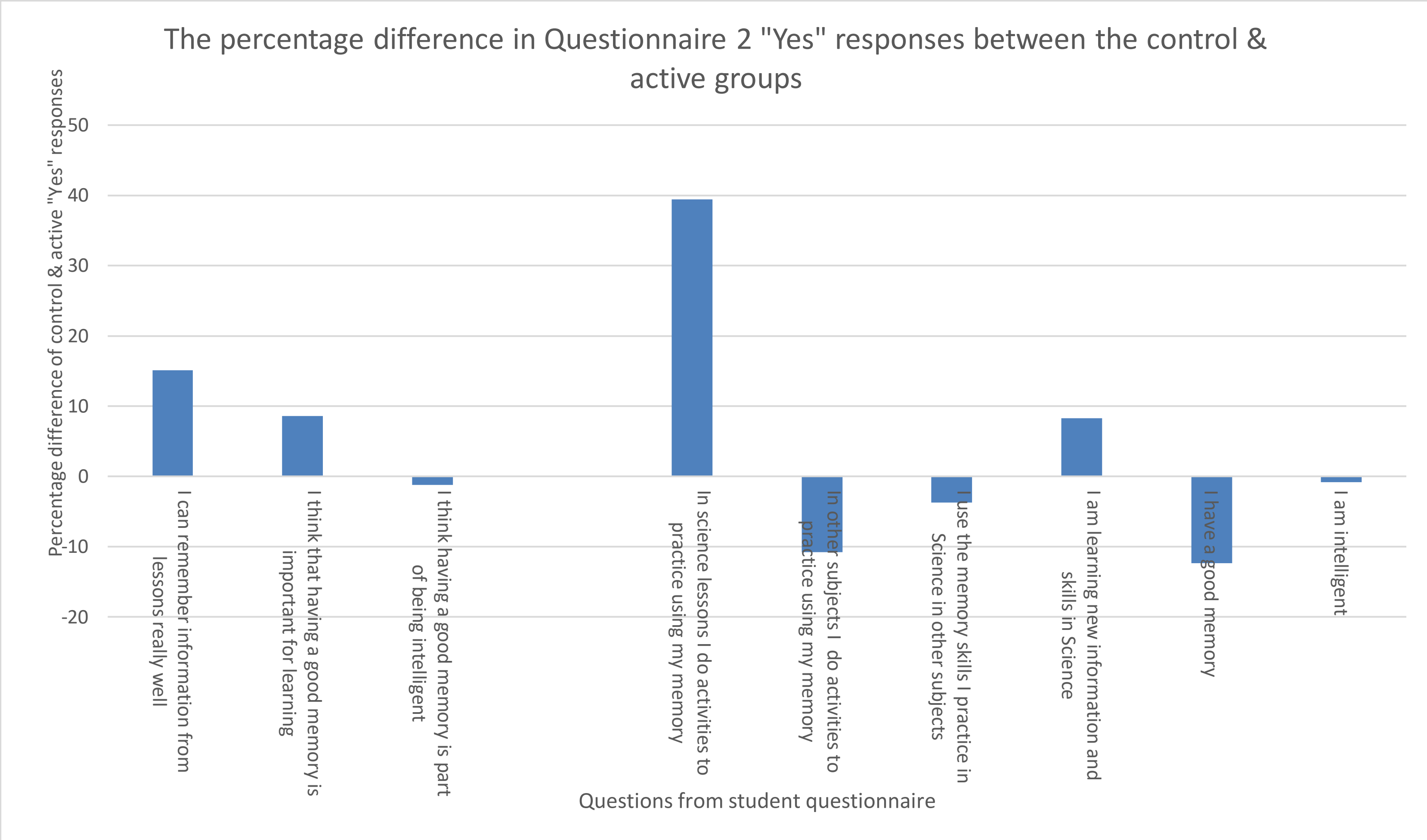


Figure 32 The percentage difference in Questionnaire 3 "Yes" responses between the control & active groups

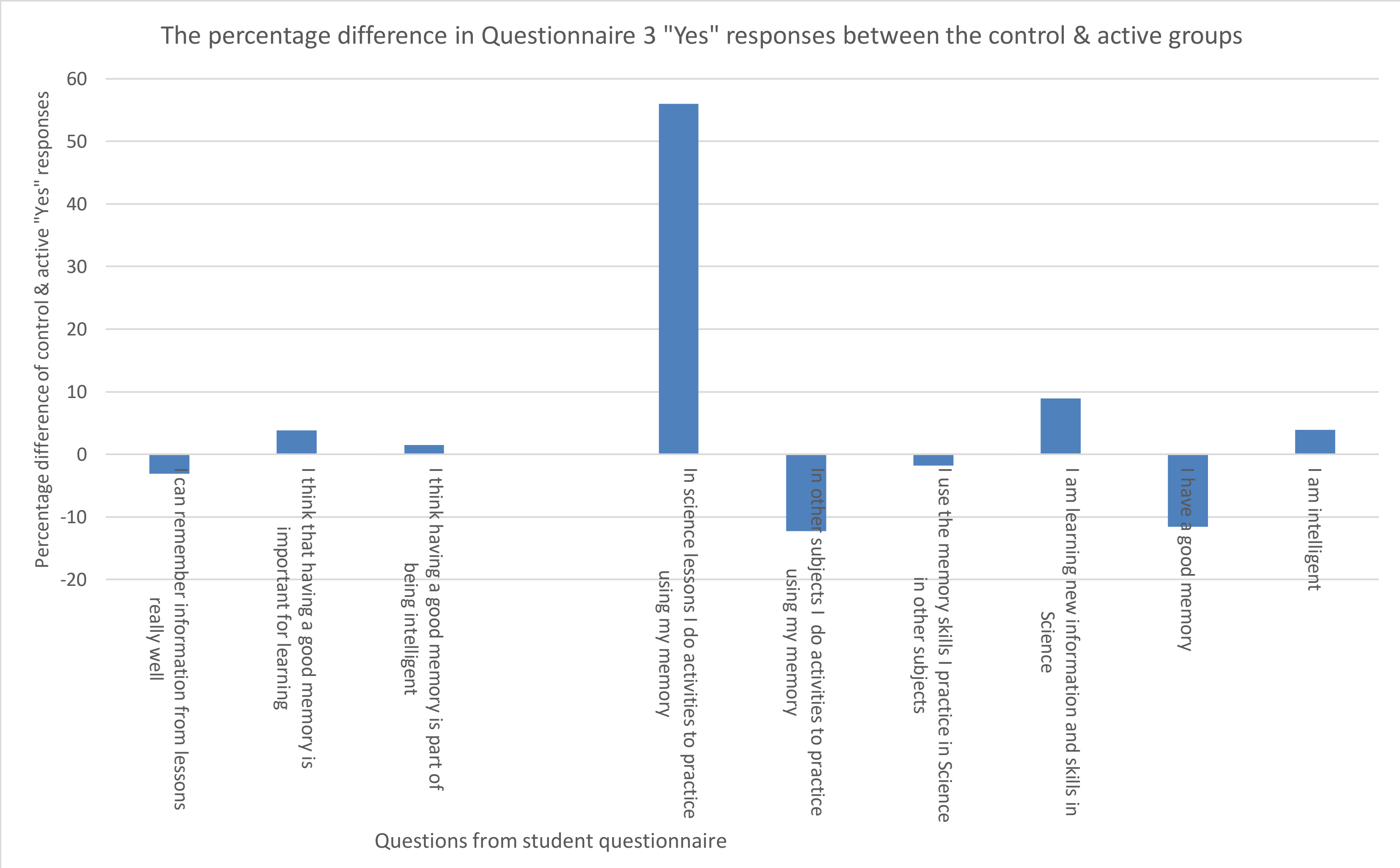
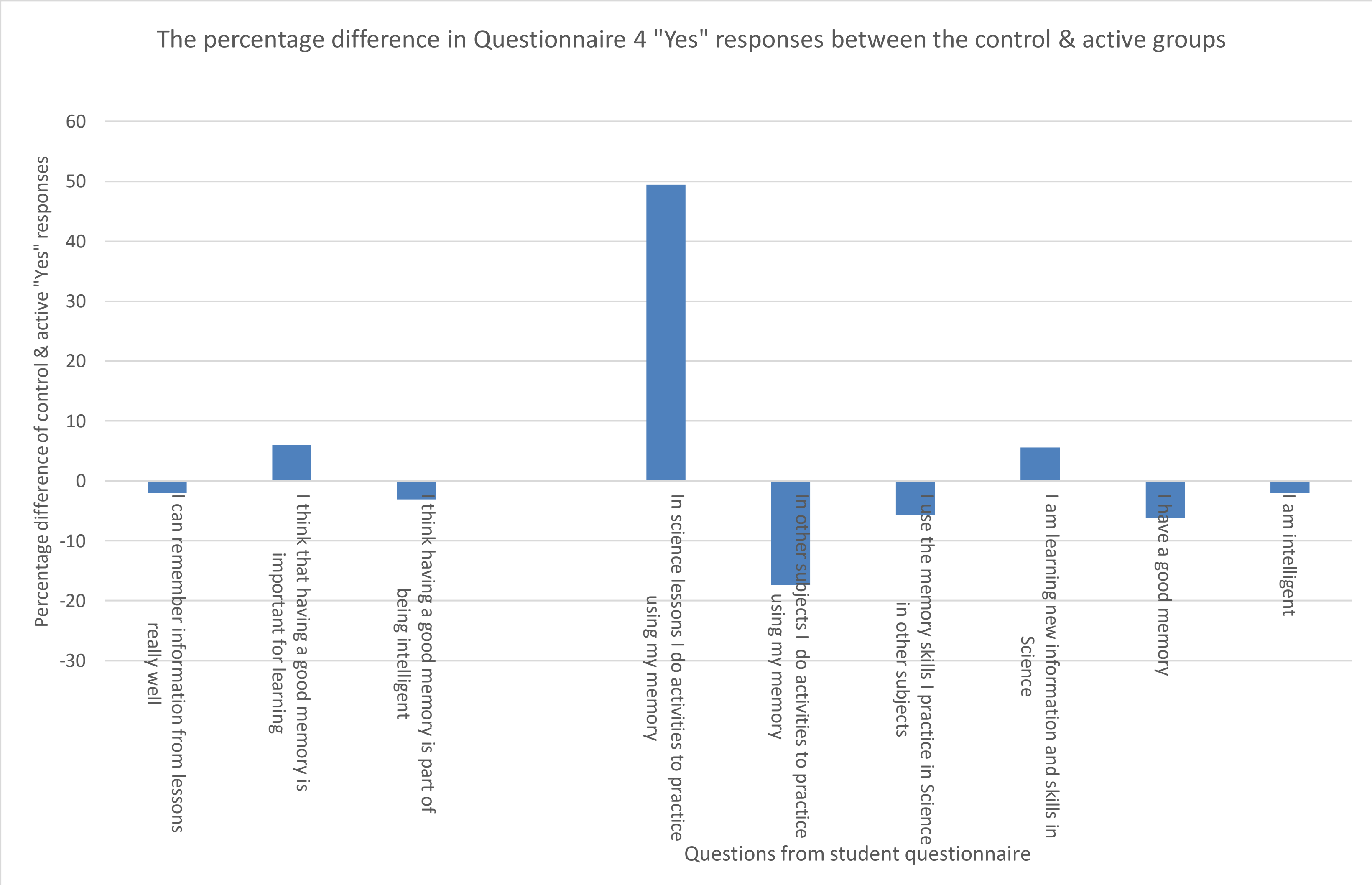


Figure 33 The percentage difference in Questionnaire 4 "Yes" responses between the control & active groups



The student questionnaire responses were also compared at each data collection point this is shown in Table 21 and in more detail in Figures 30-33. Then the differences in the responses between the active and the control students were compared throughout Year 7 (questionnaires 1 & 2) and Year 8 (questionnaires 3 & 4). The active students report being able to "remember information from lessons well" in questionnaire 2 compared to questionnaire 1 with a positive difference of 6.8 % increasing to 15.1%. Hence this positive difference in the active group students' perception of their learning increases in Year 7 and declines slightly in Year 8. This tentatively suggests that the activities to develop WM, may have an impact on the cognition of the active students' perception of their learning.

When analysing the responses to the statement "I think that having a good memory is important for learning." All the questionnaires throughout Year 7 and 8 show a positive difference in the active group compared to the control group. The positive difference in questionnaire 2 was 8.6% and the positive difference in the questionnaire 4 was 6.0%. This tentatively suggests that the activities to develop WM may have an impact on the active group's cognition that may influence their perception of memory and learning (Tables 27 & 28, p. 230 & 236, Figures 27-34).

Figure 34 The percentage difference of all four questionnaires for the "A bit" responses between the control & active groups for the question “I think that having a good memory is part of being intelligent”

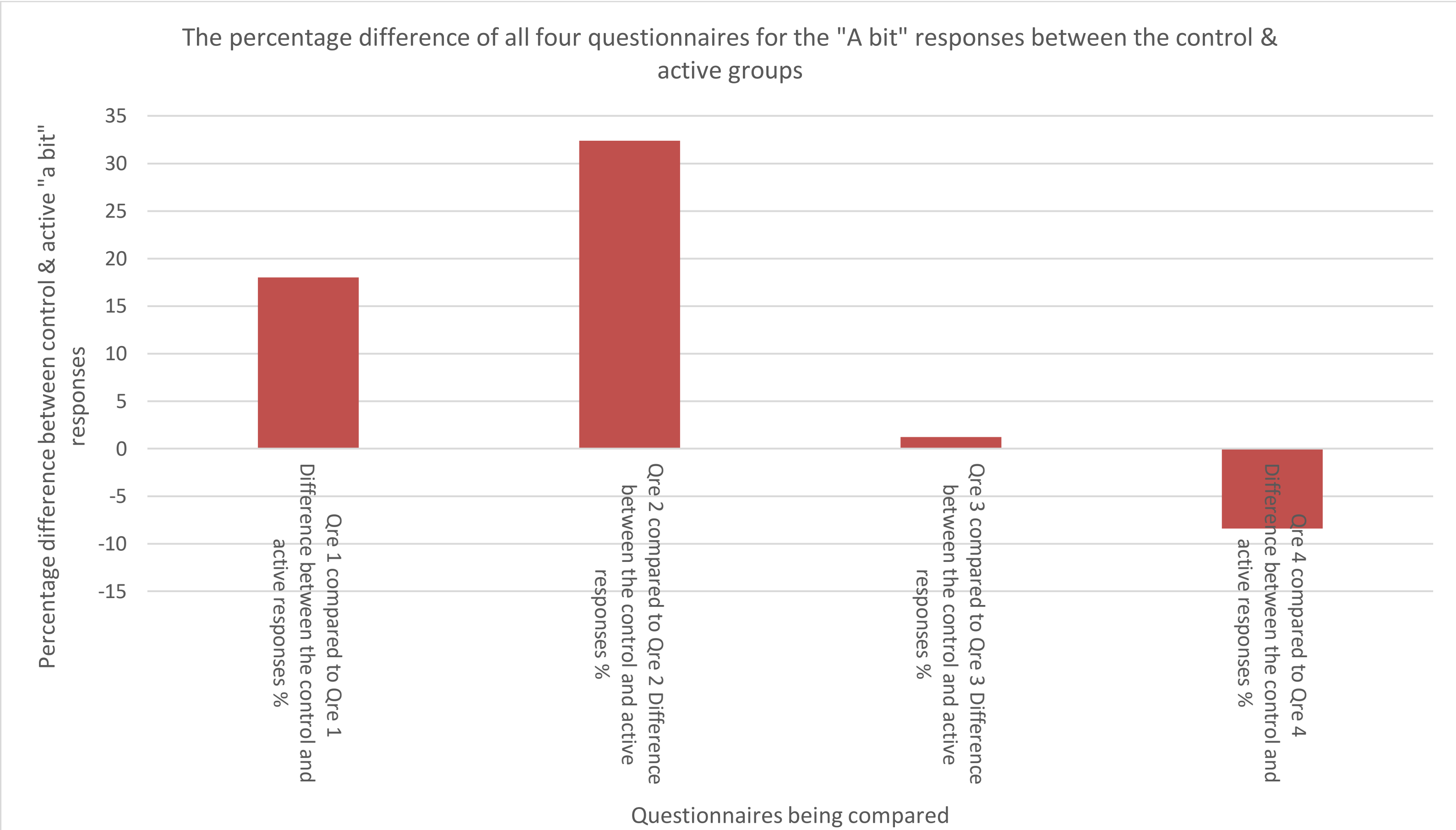


Figure 34 shows an interesting shift in active students' positive comparative response to the statement "I think that having a good memory is part of being intelligent". At the end of Year 7 questionnaire 2 the positive comparative response has increased for the response "a bit" by 32.4%. This increases by a small amount in the first half of Year 8 by 1.5%. This indicates that during that time in the study the active students' perception of memory and intelligence was more positive in Year 7 than in Year 8 (the second year of the study). This may tentatively suggest that a Science specific WM intervention may have more impact on student cognition and hence their perception of memory and intelligence in the early part of KS3 Secondary Education (Year 7) than later years.

Figure 35 The percentage difference of all four questionnaires for the "A bit" responses between the control & active groups for the question “I use the memory skills I practice in Science in other subjects”.

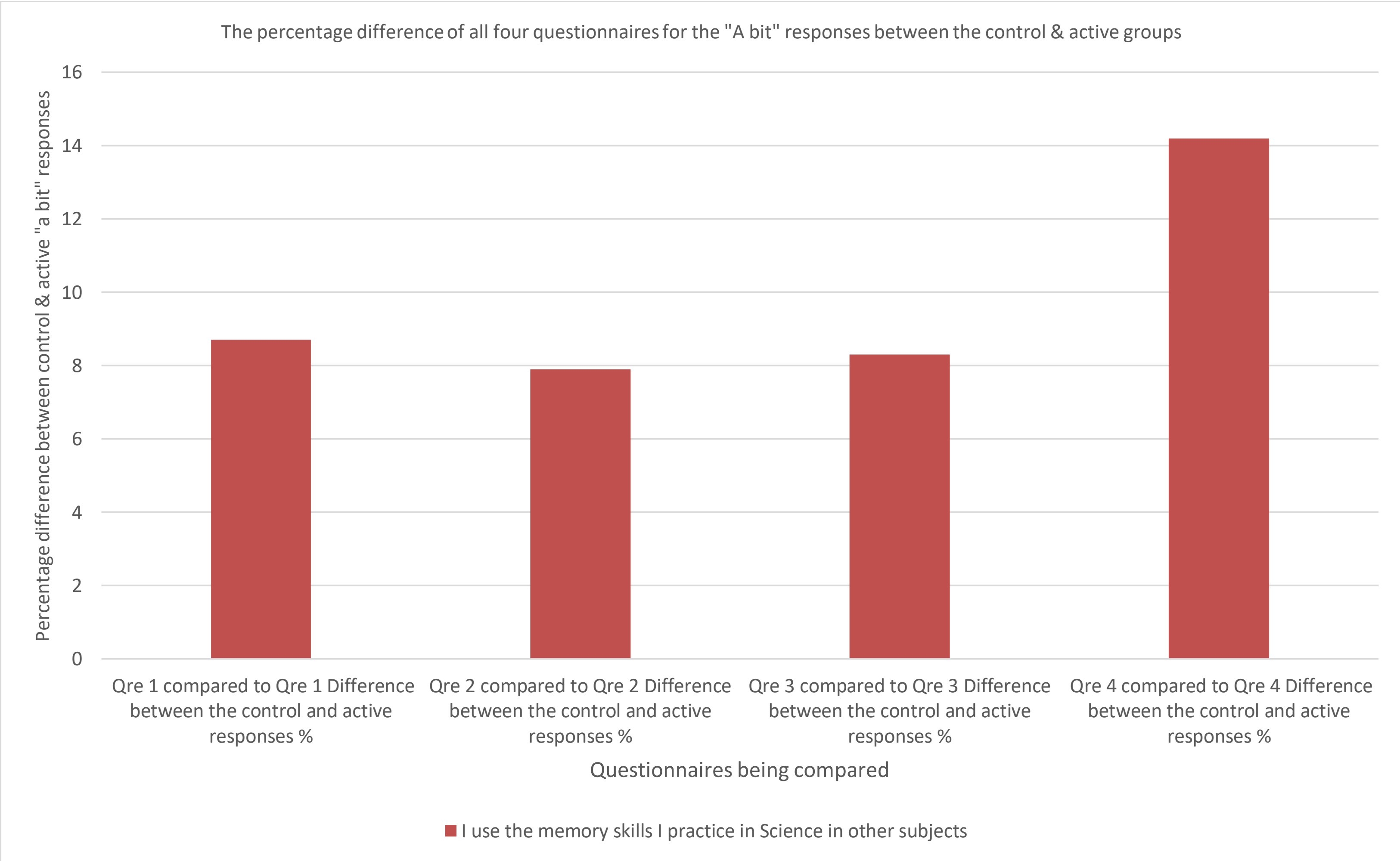


Figure 35 shows the comparative responses in the questionnaires to the statement “I use memory skills I practice in Science in other subjects” do tentatively indicate that far transfer of memory skills may be occurring for the active group students. The “a bit” positive response increases from 4.7 % difference in questionnaire 1 to 14.2% increase in questionnaire 4. This may indicate that WM activities skills gained by the active group students then may be used to have a positive change in WM in other subjects.

The comparative responses to questionnaires also suggest that active students’ perception of their attainment is more positive throughout the two-year study compared to the control group. In response the statement “I am learning new information and skills in Science” a positive difference in the active group compared to the control group in questionnaire 1 was 16.7%, in the comparison of questionnaires 2 and 3 and was 5.6% for questionnaire 4. (Table 27 & 28 p. 230 & 236, Figures 27-35, p. 236-248) However, there was little comparative difference in response for the statements “I have a good memory” and “I am intelligent”. Overall, the key findings tentatively indicate that the activities to develop WM, may have an impact on active students’ cognition that links to a more positive perception of learning in Science.

4.3.4 Analysis of lesson observations across the two years of the study

There were six classes included in the study. Three classes in the active group and three classes in the control group. I observed at total of 50 lessons during Year 7. This was from mid-October to June (due to the timing of the baseline and end of year Working Memory Tests). The active classes had in total 25 lesson observations, and the control classes had in total 25 lesson observations.

The lesson observations indicated that active group had a similar experience with two classes doing the listening, reading, and writing activities in nearly all lessons, with the remaining class following the activities but this becoming more irregular as year seven progressed. The teacher of this class using memory activities in some lessons to start lessons, practical instructions and for packing away but not using the structure as they were requested to do so at the start of the study. The observation of the third active class not having the same exposure to the activities to develop WM than the other two active classes was both supported by the data from the Science teacher questionnaire (see Appendix F) and the Teaching Assistant Science Questionnaire (see Appendix F).

The lessons observations indicated that the control group also had a similar experience. There was an equity of experience between the three classes. All the three classes had a “normal way of teaching.” One of the control classes regularly used the reading sheets, these are part of the activities to develop WM that the active group students are exposed to. However, the teacher had previously been involved in Working Memory action research and was convinced of the efficacy of the reading sheets as a teaching strategy. The impact of this is discussed in Chapter 5.

4.3.5 Analysis of Science Teacher Questionnaire Responses over the two years of the study

The Year 7 Science teachers completed a questionnaire (Appendix G) once a term. The questionnaires were all completed after the study started. The statements the Year 7 Science teachers responded by ticking the most appropriate box can be seen below. The teachers also had an opportunity to add further comment. There are only six teachers so their responses will be given in frequencies. However, in the control group one of the teachers did not fill out a questionnaire as they were off sick for a number of weeks.

The statements in the Science teacher questionnaire: -

- I follow the lesson structure to develop working memory
- I do 3 listening activities in a lesson
- The students read the differentiated reading sheets
- The students write down what they have learned with only the sentence starters to support them if needed

- I give students examples of memory techniques to help them with activities in the lesson
- After the listening activities I review the students progress explicitly
- Students are given opportunities to think about their memory and how it helps them to learn
- I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods
- I use activities to develop working memory with other year groups

In Year 7 each class was taught by only one teacher, so there were 3 active group teachers and 3 control group teachers. However, one of the control groups was taught by two teachers as there was a maternity cover teacher and a returning from maternity leave teacher. In addition, one of the active group classes was taught by a student teacher for some of the lessons. The student teacher followed the lesson structure to develop WM.

In Year 8 four of the classes were taught by just one teacher. Two of the control group classes were shared groups, where four lessons per fortnight were taught by one teacher and two lessons by another teacher. In addition, two of the teachers were teaching two of the Year 8 classes. Both of these teachers taught one in class the active group and one class in the control group. One of these control groups was also a shared group – where the teacher teaching four lessons per fortnight was also teaching a Year 8 active group for all six lessons per fortnight.

The Science teachers' questionnaire outcomes indicate that for both years of the study the active group teachers are completing the activities (in the lesson plan/structure) to develop WM, whereas the control group are not using the WM activities in their lessons. This supports the data from the lesson observations. There is evidence in Year 7 that one Science teacher of the active group students did the WM activities less as the year went on and this is also indicated in both the lesson observations and the Science TA questionnaires. Overall, the data suggests that the active group were exposed to the activities to develop WM and the control group were not exposed to the listening and writing aspects of the activities to develop WM. Hence, this lends some validity to any conclusions drawn, but due to the leakage of the activities to develop WM reading sheets leaking into the control condition, conclusions should be tentative. Furthermore, any interpretation of the data should be approached with caution.

The more detailed analysis of how the activities to develop WM were delivered in the lessons to the active group further supports this. Specifically, the active group teachers over the two years were completing at least 1-2 listening activities each lesson with the majority of active group teachers managing 2 the majority of the time (See Appendix F). The control group did no listening activities. The active group students were reading the differentiated reading sheets in the vast majority of lessons, with extreme regularity. On the other hand, the control group students were reading the reading sheets but this was much less frequently in Year 7 and with more regularity in Year 8. Furthermore, in Year 7 the active group were writing down what they had learned with minimal support in the majority of lessons. The control group were doing this much less frequently and in a less structured manner, this was evidenced from lesson observations and student questionnaires (Appendix G). In Year 8 there is shift where both the active and control group are writing down what they have learned at the end of the lesson with similar regularity. However, the active group are doing this with more structure this was evidenced from lesson observations and student questionnaires (Appendix D and E).

The Science teachers in the active group were simply asked to follow the activities to develop WM and the control group teachers were asked not to. However, because historically as a department the activities to develop WM have been used by many of the teachers for previous Year 7 cohorts; I as the researcher was aware that there were other teaching strategies that occurred as a result of delivering the activities to develop WM. I included questions to investigate if this occurred for the active group during the study. The aim was to give a more rounded view of the experience of the active group.

Over the two years of the study the active group teachers reported much more regularly than the control group teachers; giving students examples of memory techniques to help them with activities in the lesson. The active group teachers also gave the students much more regular opportunities to think about their memory and how it helps them to learn. Furthermore, in the large majority of the active group lessons the teacher reviewed explicitly how well the students had done in the listening activities (as previously mentioned this is not part of the activities to develop WM). The tables of results can be found in Appendix E.

In summary analysis of the Year 7 & 8 Science teacher questionnaires clearly shows that the active group had a very different experience in line with the activities to develop WM, with added memory techniques and opportunities to think about their memory's involvement in learning. The control group did not do the activities to develop WM, and were exposed to reading sheets, memory techniques and opportunities to think about their memory's involvement in learning much less frequently.

Chapter Five Discussion

5.1 Introduction

The discussion looks at the key findings of this study; answering each of the research questions a.-e.(RQ) in turn (see below).

What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?

Which can be separated into five distinct questions.

a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on Science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, Science and learning in Science compared to the control conditions?

e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

The results indicate that there are five key findings:

- Activities to develop WM have not made a significant difference to the active groups' post-test WM when compared to the control group (Table 11 & Table 12 p. 195 & 196) .

- There is no difference in terms of attainment (independent t-tests) but in the active group there are some conceptual links (correlation) in cognition between WM and students' knowledge and understanding of Science. Furthermore, the regression analysis of the end of Year 7 report grade suggests that WM has a 23.4% contribution to the end of Year 7 report grade. This lends some strength to the tentative finding that in early KS3 Secondary School Education (Year 7), WM intervention may be making conceptual links (correlation) of cognition between WM and students' knowledge and understanding of Science but not their Science investigative skills. The key findings tentatively suggest that the normal way of teaching may be having an impact on the cognition of control group students in specifically the knowledge of Science investigative skills.(Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figure 22-24, p. 202-203; Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 25-26, p.205; Dependent t-test results Tables 124-137 in Appendix H p. 561-580 Tables 18-20 p. 212-218)
- The activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons (Figure 35, p. 248 & Tables 21 & 24, p. 221 & 225)
- The activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33, p. 236-244; Tables 21-28 p. 221-236)
- The activities to develop WM may have an impact on the cognition of the active group students, which may lead them to think metacognitively differently to the control group students (Figures 27-33, p. 236-244; Tables 22-28 p. 224-236)

The discussion will reflect on the key findings from the study including both significant and non-significant results. The key findings from this doctorate will be discussed in relation to the theory from the literature review, the theoretical framework (Figure 13) and the seven key constructs from the literature review (see below):

1. Underachievement in secondary science
2. WM
3. WM is necessary for learning to take place
4. WM can be developed (has neuroplasticity)
5. People who complete specific activities can increase their WM
6. Increasing WM increases (Science) attainment
7. Completing specific activities in the classroom can increase WM and hence increase (Science) attainment.

In each section the significant and non-significant key findings from the quantitative and qualitative data will be considered separately and then these will be brought together at the end of each section. The quantitative and qualitative data will be integrated at the end of each section to synthesise, analyse, and evaluate the key findings. Finally, there will be a conclusion that reflects on the key findings of the overall research question (see above), contributions to the field of WM research and the wider implications of the study

5.2: A discussion of the key quantitative and qualitative findings in answering research question a. taking into full consideration the theory and findings from the literature review and the theoretical framework.

The overall key finding in answering research question a. inferential statistics of independent (unpaired) t-tests were conducted. The results of those independent t-tests were that the activities to develop WM have not made a significant difference to the active groups' post-test WM mean compared to the control group mean. The key findings of the quantitative and qualitative data will be discussed in this section, in relation to research question a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions? The findings from the quantitative and qualitative data will then be integrated and discussed taking into full consideration the theory and findings from the literature review and the research theoretical framework.

The four key constructs linked directly to RQ a. from the literature review are WM, WM is necessary for learning to take place, WM has neuroplasticity, students who complete specific activities can increase their WM. These four key constructs need to be considered within the research framework and in light of the key findings from the quantitative and qualitative data.

5.2.1: The key quantitative findings in answering research question a.

There was no significant difference between the WM of the active group when compared to the control group (Table 11 p. 195 and Table 12 p.196). An independent t-test was conducted on the post-test WM assessment data and there was no difference in the means between the active group and the control group. The WM assessment means increased for both groups when comparing the pre-test to the post-test means but this difference was not significant. This would indicate that the activities developed to increase WM do not have an impact on the size students' WM. However, the fact that both the active and control groups' WM increased demonstrates that the activities developed to increase WM do not have a negative impact on students' WM.

Hence, this indicates that WM may not be significantly improved in students completing activities to develop WM in their Science lessons compared to the students who had the normal way of teaching. The t-test findings are listed in detail in Appendix H p. 511-520 This is a key finding in helping to answer RQ a. However, it is important to note that the findings from the data analysis to answer RQ b. do indicate that the active group have some conceptual links (a correlation) in cognition between WM and students' knowledge & understanding of science. This is addressed in Sections 5.3.

5.2.2: The key qualitative findings in answering research question a.

The students were asked about their memory in the student questionnaire. The students responded to the statement “I have a good memory.” Comparing responses in questionnaires 2-4 with questionnaire 1 there was little comparative difference in response to this statement for the active or control group (Tables 27 & 28 p. 230 & 236, and Figures 27-33 p. 236-244).

5.2.3: A discussion of the key findings from the quantitative and qualitative data integrated to answer research question a.

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science, with one of the aims being to increase the WM of the active group students.

The overall key finding in answering research question a. is that the activities to develop WM have not made a significant difference to the active groups’ post-test WM compared to the control group. The four key constructs linked directly to RQ a. from the literature review are WM, WM is necessary for learning to take place, WM has neuroplasticity, and students who complete specific activities can increase their working memory. These four key constructs will be considered within the research framework and in light of the quantitative and qualitative data.

The key findings from this study are different to the findings in the literature that were also conducted in schools. WM training was shown to increase WM in students in kindergarten (Blair & Raver, 2014),in primary school age students (e.g., Cunningham & Sood, 2016; Holmes & Gathercole, 2014; Rode, Robson, Purviance, Geary, & Mayr, 2014; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010) and secondary school age students (Aries, Groot, & van den Brink, 2015).

One explanation for my findings differing from those in the literature could be the method of measuring WM was different to those used in the literature. It is also a concern that the WM assessment used was not accurate, because the students had to complete the Lucid Recall WM assessment (St. Clair-Thompson, 2015) independently on a computer with one adult administering the test for a class of 22-27 students.

The studies in the literature use a number of different ways of measuring WM. The automated working memory assessment (AWMA) was used by three of the studies referenced in the previous paragraph (e.g., Cunningham & Sood, 2016; Holmes & Gathercole, 2014; Rode, Robson, Purviance, Geary, & Mayr, 2014). Blair and Raver, (2014) used the WM forward and backward digit span (Blair & Raver, 2014). Where as, St Clair Thompson et al. (2010) used the WM test battery for children (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010) and Aries et al. (2015) used a History specific n-back test and odd one out test (Aries, Groot, & van den Brink, 2015).

The AWMA test was my preferred test when I conducted the research into WM testing (Appendix B). I knew it had been used in research where effective WM training had taken place in schools. The school where the research was conducted also had a member of staff trained on how to administer AWMA. But it was not available for purchase at the time of the study. However, it is worth noting that the testing using AWMA would also have been time consuming with n=182 cohort of participants.

Due to budget constraints. I had no funding to conduct the research so I had to choose a WM test that was standardised, could be administered to a large number of students with minimum use of a trained members of staff and all at minimum cost. Consequently, this study was conducted using the Lucid Recall WM Test (St. Clair-Thompson, 2015).

When planning the method of the study, I dedicated a significant amount of time to finding a cost effective, efficient, and rigorous way to measure the WM (Appendix B has a comprehensive review of my findings). There is no doubt that there are more accurate and rigorous tests that could be done individually with students. If cost and time had not been an issue my preferred test (that is still currently available) would have been TOMAL 2 (Reynolds & Voress, 2007). This would have had to be administered one to one by a trained teacher. This would have had the aim of generating data that was a more accurate measure of the students' WM pre-test and post-test.

An alternative explanation for my findings being different from other studies in the literature is that the activities developed to train WM in a domain specific way are having an impact on the cognition of the active students' WM, that are equivalent to the impact the normal way of delivering lessons is having on the cognition of the control students' WM. So, the cognition of the WM of both groups of students changed; due to both the active and control conditions both taxing WM but in differing ways. In reviewing the literature several studies reported findings that WM is important for learning within a school setting, and that aspects of a normal Science lesson would tax WM, (Carretti, Re, & Arfe, 2013; Cowan, 2014; Gathercole, Pickering, Knight, & Stegmann, 2004; Kellogg, 2001;Olive, 2004; Packiam Alloway & Alloway, 2015; Service & Turpeinen, 2001).

Kellogg, (2001) and Olive, (2004) both report that writing taxes the WM of school aged students (Kellogg, 2001; Olive, 2004). Similarly, Service & Turpeinen's (2001) reported that spelling involves and hence taxes WM, and that spelling was more than just the cognitive process of changing the mental thought of the letters into the written output of the letters (Service & Turpeinen, 2001). In line with this, Carretti et al., (2013) report that WM is a differentiator of reading comprehension and writing (Carretti, Re, & Arfe, 2013).

Furthermore, Gathercole et al., (2014) report that when school-aged students complete mathematics in lessons they experience cognitive overload that taxes the WM (Gathercole, Pickering, Knight, & Stegmann, 2004). Similarly, Packiam-Alloway & Packiam, (2015) report that WM is a differentiator of Science attainment and henceforth, that aspects of classroom activities such as reading, writing and mathematics tax WM (Packiam Alloway & Alloway, 2015). This is further supported by Cowan, (2022) who argues that if cognitive load is too low then learning will not take place, and if cognitive load is too high WM is overloaded and learning cannot take place. Hence, cognitive load must be at a sufficient (and specific) level to ensure WM is taxed just enough for learning to take place (Cowan, 2022).

The literature supports the idea that taxing WM leads to an increase in WM, this finding has been reported by Holmes et al., (2009) where the WM training used was adaptive (Holmes, Gathercole, & Dunning, 2009). The adaptive WM training taxes the WM a little more each time the participant increases their level. This finding has also been reported in the later study by Munez et al., (2022) who used adaptive WM training to conduct a large-scale WM training and numeracy intervention study (Muñez, et al., 2023).

The normal way of working Science lessons experienced by the control group would have included reading, writing and mathematics which tax the WM. These normal lesson activities would have increased in difficulty moving through the two-year study; this could cautiously be suggested as an adaptive form of training that taxed the WM. This is another possible tentative explanation for the outcome of there being no significant difference in the post-test WM assessment between the active and the control group. Both the active and control conditions had an impact on the students' cognition of WM.

Building on the former possible explanation for my findings in answering RQ a. being different to the findings in the literature; is the leaking of the activities to develop WM (the active group condition) into the control group. Leakage of this happened in Science but could also have occurred in other subject areas in the school. This is evidenced in the responses to the Science Teacher Questionnaires (p. 248-251 and Tables 69 & 79, p. 453 & p. 462), Science Teaching Assistant

Questionnaires (Tables 86 & 87, p.467 & p. 469) and the Whole Staff Questionnaires (Tables 89-94, p. 470-480).

The fact that the control group have been exposed to the reading sheets with increasing regularity (part of the active group's intervention) may have had an impact on the WM increase of the control group. The literature supports this with the use of domain specific literature being an effective strategy in classrooms (e.g., Kuin Lai, Wilson, McNaughton, & Hsiao, 2014; McDonald Connor, et al., 2010). Furthermore, the literature supports WM size being linked to reading ability and that reading may supports WM development (e.g., Berninger, et al., 2010; Carretti, Re, & Arfe, 2013).

The theoretical framework including both quantitative and qualitative data gathering has enabled the outcome of the post-test WM assessment to be discussed on different strata and with alternative explanations that are in line with the findings of this study and in the literature. However, it also, important to draw attention to the impact the Covid-19 pandemic had on the WM assessment in this study. The Lucid Recall assessment (St. Clair-Thompson, 2015) at the end of Year 8 could not take place due to the pandemic causing partial school closure. When the school re-opened in September 2020, we were constrained by the Covid-19 regulations. Year groups were only allowed in certain parts of the school at certain times of the day and week; meaning the IT suites could not be accessed.

Furthermore, the person trained to administer the Lucid Recall Tests was an unpaid volunteer and although DBS checked, during this time no visitors were allowed to come into the school. So, there was no opportunity to complete the Lucid Recall Testing during the participants Year 9.

In summary, the findings to answer RQ a. are somewhat disappointing with no significant difference between the post-test WM assessment means of the active group when compared to the control group. Furthermore, due to the leakage of the active group's reading sheets into the control group conditions these findings are difficult to interpret. The findings have been tentatively explained by the lack of rigorous WM assessment with a proven track record in WM training research, or the normal way of teaching control group having the same impact on student cognition in WM as the active group with the lessons embedded with the activities to develop WM.

5.3: The key findings from the quantitative data in answering research question b. taking into full consideration the theory and findings from the literature review and the theoretical framework.

The overall key finding in answering research question b is, there is no difference in terms of attainment (independent t-tests) but in the active group there are some conceptual links (correlation) in cognition between WM and students' knowledge and understanding of Science. Furthermore, the regression analysis of the end of Year 7 report grade suggests that WM has a 23.4% contribution to the end of Year 7 report grade. This lends some strength to the tentative finding that in early KS3 Secondary School Education (Year 7), WM intervention may be making conceptual links (correlation) of cognition between WM and students' knowledge and understanding of Science but not their Science investigative skills. These key findings may tentatively suggest that the normal way of teaching may be having an impact on the cognition of the control group students in the knowledge of Science investigative skills.(Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figure 27-29 p.236-238; Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 25-26, p.205; Dependent t-test results Tables 124-137 in Appendix H p. 561-580 & Tables 18-20 p. 212-218),

The key findings from the quantitative data will be discussed in this section (as research question b. focuses on attainment there was only quantitative data in the key findings). What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions? The key findings from the quantitative data will then be discussed taking into full consideration the theory and findings from the literature review and the research theoretical framework.

The three key constructs linked directly to RQ b. from the literature review are underachievement in science, increasing working memory increases science attainment and completing specific activities in the classroom can increase WM and hence increase (Science) attainment. These three key constructs need to be considered within the research framework and in light of the key findings from the quantitative and qualitative data.

5.3.1: A discussion of the key findings from the quantitative data in answering research question b.

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science, with one of the aims being to increase the attainment of the active group students compared to the control group.

The Science attainment was measured in summative tests (Year 7 tests 1,2,3 and end of year test, Year 8 tests 1,2,3 and end of year test), Science skills (planning, obtaining evidence, analysis and evaluating), Science homework (biology, chemistry, physics) and the summative end of year report.

In order to understand these findings fully it is important that I am explicit about what content and skills each aspect of Science attainment was measuring. The summative tests and homeworks were testing the knowledge and understanding of Science curriculum content. The Science skills assessments were assessing the students' practical skills; specifically, their ability to plan an investigation, gather and record data, analyse their own data, draw conclusions, and evaluate their method and data. The end of Year grade is a holistic grade awarded based on how the student has progressed using the data from all the Science assessments and teachers' professional judgement. In short, the Science summative tests and homeworks were measuring different knowledge and skills than the Science investigative skills assessments. The only attainment measure that looked at the Science attainment in its' entirety was the end of Year report grade.

Correlations were used to look at the relationship between WM and Science assessment. The correlations between the post-test WM assessments and the Science Assessment Attainment were conducted. The r value was checked against that of the pre-test WM assessment correlations with the Science Assessment Attainment data. The correlations for the post-test data were only deemed to be significant if the pre-test correlations were not significant or the pre-test correlations r value was less than the post-test correlation r value.

The post-test WM assessment and Year 7 test 1, Year 7 test 3 and the end of Year 7 report grade was a positive significant correlation for the active group but not the control group (Table 13 p. 202). In addition to which, regression analysis was undertaken for the active group, WM was shown to be contributing 23.4 % to the end of Year 7 report grade. The control group, WM was shown to be contributing 3.3% to the end of Year 7 report grade (Table 14 p. 204). Furthermore, the end of Year 8 report grade was a significant positive correlation for the active group and not the control group (Table 15 p.206). On the other hand, regression analysis was undertaken for the active group, WM was shown to be contributing 26.9 % to the end of Year 8 report grade but the control group, WM was shown to be contributing 24.5% to the end of Year 8 report grade (Table 16 p. 207).

However, the majority of correlation tests to investigate the relationship between WM and Science attainment measures were not significant. There were relatively few significant correlations (Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 25-26, p.205;) and where there was a significant correlation for the active group the control group would have a significant correlation for a different attainment measure for that type of assessment e.g., homework or investigative skills (Tables 17 & 121 p. 208 & 556 & Figures 25-26, p. 205).

The independent t-tests to see if there were differences in the means of the control group compared to the active group were conducted on the attainment measures (Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figures 22-24 p. 202-203). There were very few significant differences between the active group means compared to the control group's means. Where significant differences did occur, the active group would be significantly higher for one measure and the control group would be significantly higher for a different measure (Figures 22-24 p.202-203).

Dependent (paired) t-tests were conducted between baseline data and the assessments for the control group and the active group. The p-values were compared between the control and the active group to see if this could shed some more light on whether the activities were or were not having an impact on Science attainment.

The control group had more significantly different means compared to the active group for 8 of the 21 investigative skills assessments (Table 19 p. 214, Tables 126-133, p. 565-577). On the other hand, the active group had more significant means compared to the control group for 4 out of the 7 summative tests (Table 18 p. 212, Tables 124 & 125, p. 561 & 563) and for the chemistry homework (Table 20 p. 218, Tables 134 & 135, p.578 & 579).

Overall, the presence of a large number of non- significant differences (from independent and dependent t-tests and no significant relationships (from correlation tests) when the inferential statistical analysis of the data was completed, using independent and dependent t-tests and correlation tests must lead to a tentative conclusion. There is no difference in terms of attainment (independent t-tests) but in the active group there are some conceptual links (correlation) in cognition between WM and students' knowledge and understanding of Science. Furthermore, the regression analysis of the end of Year 7 report grade suggests that WM has a 23.4% contribution to the end of Year 7 report grade. This lends some strength to the tentative finding that in early KS3 Secondary School Education (Year 7), WM intervention may be making conceptual links (correlation) of cognition between WM and students' knowledge and understanding of Science but not their Science investigative skills. The key findings tentatively suggest that the normal way of teaching may be having an impact on the cognition of control group students in the knowledge of Science investigative skills.(Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figure 27-29, p. 236-238; Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 25-26, p. 205; Dependent t-test results Tables 124-137 in Appendix H p. 561-580 & Tables 18-20 p. 212-218)

The findings for RQ b. have three possible explanations. The literature is divided when it comes to near transfer effects of WM training. Furthermore, there is literature that has findings to support increased Science attainment without being linked to WM or WM training. These explanations must interpret the findings of this study with with caution. This is because of the divided and sometimes contradictory findings reported in the literature, alongside the many non-significant findings from the Science attainment data analysis in this study. The three possible explanations are discussed below.

The first tentative explanation for the findings to answer RQ b. is that the active and control conditions have changed the cognition of the students' WM (see section 5.2). This is due to the active group conditions leaking into the control group conditions (as discussed in section 5.2.3). This has led to a positive impact on cognition for the active group students' WM and its' link to Science knowledge and understanding compared to the control group. This has led to a positive impact for the on the cognition of the control group students' WM and its' link to Science investigative skills compared to the active group. There are some findings in the literature that support the explanation that an increase in WM, after WM training also show increases in attainment e.g., (Diamond & Ling, 2016) (Titz & Karbach, 2014) (Karbach, Strobach, & Schubert, 2015) (Studer-Luethi, Toermaenen, Margelisch, Hogrefe, & Perrig, 2022) (Johann & Karbach, 2020) (Holmes & Gathercole, 2014). In the literature Johann and Karback, (2020) and earlier literature from Karbach et al. (2015) report findings that support WM training, increasing WM and domain specific near transfer effects showing an increase in reading attainment but not in maths (Johann & Karbach, 2020). (Karbach, Strobach, & Schubert, 2015).

Conversely, Studer-Luethi, et al. (2022) report findings that support WM training increasing WM and domain specific near transfer effects showing an increase in maths attainment but not in reading (Studer-Luethi, Toermaenen, Margelisch, Hogrefe, & Perrig, 2022). Whereas, Holmes & Gathercole, (2014) report findings that support WM training increasing WM and near transfer effects showing an increase in maths and English attainment (Holmes & Gathercole, 2014).

This is consistent with the findings from Peng & Swanson (2022) in their review of WM training where they found domain specific WM training to have near transfer effects when delivered as a specific series of activities focused on supporting students to link information to information already stored in their LTM (Peng & Swanson, 2022). Furthermore, findings from a review of the literature by Titz and Karbach (2016) report that domain specific WM training is likely to be more successful at affecting cognitive benefits than targeted computer training. This is also reported in the Diamond and Ling (2016) review. This literature supports the tentative explanation of the findings, that the cognition of WM has changed in both the control and the active group (Section 5.2) due to leakage of the activities to develop WM into the control group condition. This has led to a positive impact on cognition for the active group students' WM and its' link to Science knowledge and understanding compared to the control group. This has led to a positive impact on the cognition of the control group students' WM and its' link to Science investigative skills compared to the active group.

The second explanation for the findings to answer RQ b. must also be treated with caution. The activities to develop WM may have had a positive cognitive impact (that does not involve WM).

This has led to a positive impact on cognition for the active group students that links to Science knowledge and understanding when compared to the control group. This explanation also includes the tentative suggestion that the teachers of the control group had more time to deliver the practical demonstrations and practical lessons and follow up those lessons in more detail. This led to a positive impact on the cognition of the control group students that links to Science investigative skills compared to the active group.

There are findings in the literature to support this alternative explanation. The activities to develop WM have led to a positive impact on cognition (that does not involve WM) for the active group students that links to Science knowledge and understanding compared to the control group.

One such study which draws many parallels with this doctoral study was by Cromley et al. Cromley et al., (2016) reported findings from a study framed within cognitive science. The study was similar to this study as it was a cognitive science-based intervention with the aim of increasing Science attainment in middle-school aged students. The study had the further similarities of including the delivery of modified materials within an existing POS; and was also delivered by teachers in classrooms over a two-year period. The findings show that the intervention materials (based on improving the understanding and learning from Science diagrams) significantly improved Science attainment in comparison to control conditions (Cromley, et al., 2016). This is in line with the findings from this study.

In addition, a meta-analysis of studies whose aim was to investigate the effects of writing about Science, social science, or mathematics on learning in Science, social science, or mathematics attainment reported findings to support this explanation. The meta-analysis conducted by Graham et al. (2020) included 56 studies all with students of school age. The findings reported that writing about Science improved learning in Science for students of high school age (Graham, Kiuhara, & MacKay, 2020). The students in the active group of this doctoral study were required to write about the Science they had learned in every lesson. This may account for the finding that the active group saw a positive impact on cognition that linked to their knowledge and understanding of Science that was absent in the control group.

There are findings in the literature to support the explanation that the control group conditions have led to a positive impact on the cognition of the control group students that links to Science investigative skills compared to the active group. This is because they had more time to complete Science practical investigation work and watch teacher demonstrations of practicals. In the *"Finding the optimum: Science subject report"* a piece of research and analysis published by Ofsted 2nd February 2023 there were a number of arguments put forward for the importance of practical work in Science education. The report cites in several places the impact of lack of practical activity on Science attainment (Unknown, 2023). Literature published on the findings of research that investigated how best to teach practical work during Covid restrictions reported findings that teacher demonstrations of practical work and practical work had a greater impact on attainment compared to videos and simulations (Moore, Fairhurst, Correia, Harrison, & Bennett, 2020).

In addition to which, recent education research by Shana and Abulideh (2020) reported the finding that there was a significant difference in the attainment of students who experienced practical work when compared to those who did not; with the students who experienced practical work having higher attainment (Shana & Abulibdeh, 2020). This may account for the finding that the control group conditions had a positive impact on the cognition of the control group students that links to Science investigative skills compared to the active group.

The third tentative explanation for the findings to answer RQ b. is that the teachers delivering the lessons in both the control and the active conditions used teaching and learning strategies that have improved students' cognitive abilities. This has led to a positive impact on the cognition of the control & active group students that link to Science knowledge and understanding both in summative assessment and science investigative skills.

Prain et al., (2017) reported findings that making the Science curriculum personal to students' lives improves attainment (Prain, Waldrip, Sbaglia, & Lovejoy, 2017). The POS for KS3 Science at the research school was designed to inspire curiosity and for students to learn through experiential activities in every lesson. Both the active and control group were exposed to this POS. This included Science practical work, or demonstrations or student models or making models, hence enabling students to link the Science to their everyday lives. This may account for both the active and control group data having a large number of non-significant differences between their means for the Science attainment. As this led to a positive impact on the cognition of the control & active group students

This is further supported in the literature by Kuin et al. (2014) who reports that using general and subject specific literacy intervention in the form of directed subject reading increased attainment. This finding is consistent with that of McDonald (2010) who reported that Science specific directed reading within Science lessons improved Science attainment. The fact the reading sheets (part of the activities to develop WM in the active group condition) leaked into the control group condition means that the Science specific reading could account for the active and control group data having a large number of non-significant differences between their means for the Science attainment.

The wealth of literature on WM training was used in my theoretical framework to support the use of activities to develop WM and increase science attainment as an effective strategy to employ in the classroom. The evidence from this study goes some way to support the efficacy of this teaching strategy. The tentative finding being, that in early KS3 Secondary School Education (Year 7), WM intervention may be making conceptual links (correlation) of cognition between WM and students' knowledge and understanding of Science but not their Science investigative skills. But the evidence is very tentative; due to the significant data to answer RQ b. being limited and the large number of non-significant data the findings for RQ b. These key findings need to be treated with caution and these explanations have been suggested tentatively. This coupled with the findings from the literature being divided; this is apparent from the findings from the literature that support the three alternate explanations. This suggests that there are implications for WM research and a need for further research is required in this area (this is discussed in more detail in Section 5.7-5.10).

5.4: A discussion of the key findings from the quantitative and qualitative data in answering research question c. taking into full consideration the theory and findings from the literature review and the theoretical framework.

The overall key finding in answering RQ c. is that the activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons (Figure 35, p. 248 & Tables 21 & 24, p. 221 & 225). The key findings from the quantitative and qualitative data will be discussed in this section, in relation to research question c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions? The key findings from the quantitative and qualitative data will then be integrated and discussed taking into full consideration the theory and findings from the literature review and the theoretical framework.

The two key constructs linked directly to RQ c. from the literature review are increasing working memory increases attainment (far transfer effects of WM training) and completing specific activities in the classroom can increase WM and hence increases attainment (far transfer effects of WM training in schools). These two key constructs will be considered within the research that informed the theoretical framework and in light of the key findings from the quantitative and qualitative data.

5.4.1: The key quantitative findings in answering research question c.

When examining the quantitative data from the Year 7 and 8 student questionnaires the responses to the statement “I use memory skills I practice in Science in other subjects” do indicate that the activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons (Figure 35, p. 248 & Tables 21 & 24, p.221 & 225) (that is absent for the control group students). The “a bit” positive response increases from 4.7 % (compared to the control group) in questionnaire 1 to 14.2% increase in questionnaire 4. This is an increase from 4 students at the start of the study to 16 students at the end of the study. This data shows that a number of the active group students are using the memory skills they practice in Science in other lessons. This tentatively supports the conclusion that the activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons (Figure 35, p. 248 & Tables 21 & 24, p. 221 & 225).

5.4.2: The key qualitative findings in answering research question c.

Building on the quantitative data there is some supportive qualitative data. There were two responses from active group students to the Year 7 student interviews questions “Do you think doing memory activities in your Science class is useful for your learning? If yes why?” where the two students did not just respond about their learning in Science but also explained that the memory activities were helping them with their learning in other lessons.

Furthermore, in Year 8 there were two students from the active group who responded to the student interviews by saying that the memory activities were helping them at home and a third active group student stated the memory activities were helping them with real life (Appendix E, p.493-498). The five students’ comments tentatively support the quantitative data that the WM activities to develop WM may have far transfer effects. However, it is important to consider that there may have been another explanation for this outcome. One such explanation could be, this may have been an example of participant bias. Or some other variable has led to five students stating that the memory activities that they do in Science lessons are useful for their learning in other lessons and at home due to one of the many confounding variables of this study. The data does suggest that these five participants may have experienced an impact on their cognition that may lead to far transfer effects in either using the skills gained in other lessons, and, or in other areas of their life.

5.4.3: A discussion of the key quantitative and qualitative findings integrated to answer research question c.

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science, with a possibility that the intervention may have far transfer effects.

When the qualitative and quantitative data are integrated, the overall key finding in answering research question c. is that the activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons. The key constructs from the literature that relate to RQ c. are increasing working memory increases attainment (far transfer effects of WM training) and completing specific activities in the classroom can increase WM and hence increases attainment (far transfer effects of WM training in schools). There are two possible explanation for the findings to answer RQ c. and these will be discussed in this section.

One explanation of the findings is that the activities to develop WM have had a positive impact on the cognition that linked to the WM of the active group students (in a way that could not be assessed by Lucid Recall WM Assessment) and this may have led to far transfer effects in other lessons . There are findings in the literature to support the conclusion of WM training interventions having far transfer effects. In the literature Titz and Karbach (2016) report the findings that domain specific WM training is likely to be more successful at affecting cognitive benefits than targeted computer training. This is also reported in the Diamond and Ling (2016) review; where the Tools of the Mind WM training programme was discussed. Initially, as a 1 hour a day intervention was ineffective, when Tools of the Mind shifted to a WM training with real world activities embedded in the curriculum it had real impact on student attainment (Diamond & Ling, 2016). Blair and Raver (2014) who conducted the Tools of the Mind research, report far transfer effects in their study (Blair & Raver, 2014). This is tentative evidence to support the idea that when integrated into the classroom activities as part of the normal routine of teaching it was reported that students had a better WM furthermore, far transfer effects appear to have been demonstrated.

As stated in the literature review and above, far transfer effects are not commonly reported in WM training research studies. Dehn (2008) states that there was no chance of far or even near transfer to academic attainment unless WM training was domain specific (Dehn, 2008). There is some very tentative evidence to suggest that far transfer effects may have been demonstrated in this research study. These data however, must be interpreted with caution as no attainment data from other subjects has been analysed in this study to corroborate the evidence from the student questionnaires and interviews. Thus, there is no way of quantifying the students' questionnaire and interview responses with student attainment from other subjects the impact of the far transfer effect in this study. This is a limitation (this is considered in Section 5.7).

An alternative explanation is that the activities to develop WM have the had an impact on the cognition of the active group students in another way (e.g., other executive functions) and those skills are being practiced in other lessons. Far transfer effects findings being reported in the literature for teaching strategies and programmes to improve attainment in Science (see Chapter 2 section 2.3) were scarce with CASE being the only one who explicitly supported the occurrence of far transfer effects (Adey & Shayer, 1993); whereas, other programmes and strategies supported their ability to improve Science attainment there were no far transfer effects discussed (e.g., Pilegard & Fiorella, 2016; Sumeraki, Nebel, Kuepper-Tetzel, & Need Kaminski, 2021). CASE has demonstrated the impact of far transfer effects to the attainment of participants. Girls showing increased English attainment and boys increased Maths attainment (Adey & Shayer, 1993). These findings by Adey & Shayer (1993) do tentatively support the explanation that the activities to develop WM could had an impact on the cognition of the active group students in another way and this may be transferred to other subjects.

Further reports in the literature on WM training support the conclusion that the activities to develop WM did not cause an increase in WM (instead having an impact on the cognition of the active group students in practiced skills only and this may have caused the far transfer effects students reported had occured other lessons). For example, Van de Sande (2016) reports that computerised WM training does not demonstrate near transfer effects but that participants simply get better at the training program (Van de Sande, Segers, & Verhoeven, 2016). This finding was also consistent with a review of WM training programmes in schools by Diamond and Ling (2016) (Diamond & Ling, 2016). This is further supported by Titz and Karbach in their 2016 review of WM training programmes in schools (Titz & Karbach, 2014). This finding was also reported by Himi et al. (2022) with the only transfer gains were demonstrated in the practiced tasks (Himi, Stadler, von Bastian, Bühner, & Hilbert, 2022).

Further findings from the literature support this alternative explanation. It is reported by St Clair-Thompson et al. (2010) that WM training has near transfer effects but no far transfer effects when using a computerised WM training programme called Memory Booster (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010). This is consistent with the findings from Peng & Swanson (2022) in their review of WM training where they found domain specific WM training to have near transfer effects when delivered as a specific series of activities focused on supporting students to link information to information already stored in their LTM (Peng & Swanson, 2022).

In addition there is also no clear use of the term far transfer in the literature. So, far transfer has been used to show an increase in attainment in one subject after attainment in another subject (Adey & Shayer, 1993). However, in WM training it has been used to describe the skills practiced in the WM training intervention being used by the student in a subject area (Holmes & Gathercole, 2014) or if the WM training was specific a differing subject area (Diamond & Ling, 2016). Overall, the key finding in answering research question c. is that the activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons. This is an extremely tentative conclusion and should be treated cautiously.

5.5: A discussion of the key findings of the quantitative and qualitative data in answering research question d. taking into full consideration the theory and findings from the literature review and the theoretical framework.

The overall key finding in answering research question d. is the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and their learning in Science (Figures 27-33 p. 236-244; Tables 21-28, p. 221-236)

The key findings from the quantitative and qualitative data will be discussed in this section, in relation to research question d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory and learning in Science compared to the control conditions? The key findings from the quantitative and qualitative data will then be integrated and discussed taking into full consideration the theory and findings from the literature review and the theoretical framework. The three key constructs linked directly to RQ d. from the literature review are people who complete specific activities can increase their WM, increasing WM increases (Science) attainment and completing specific activities in the classroom can increase WM and hence increase (Science) attainment. The specific aspect of student perception of their memory and learning in Science will be the focus within these two key constructs in this section of the discussion.

The student interviews and questionnaires provided quantitative data (as well as qualitative data). These methods of data collection were particularly useful in ascertaining the perception of memory and learning Science of the students. This section synthesises the key findings from these different sources to evidence the conclusion the activities to develop WM have had an impact on the active group students' cognition and hence their perception of memory and learning Science.

5.5.1: The key quantitative findings linked to perception of memory in answering research question d.

The key finding for RQ d. is that the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. p. 236-244 ; Tables 21-28 p. 221-225). The evidence for this comes from both student interviews and questionnaires. The student interviews in Year 7 found that 92 % of the active group found the memory activities useful for their learning; this decreased slightly in Year 8 to 83%. However, still a large majority of the active group reported this positive perception of the memory activities (Tables 22 & 25, p.224 & 227).

The Year 7 & 8 Student Questionnaires were analysed for the students' perception of their memory. Comparisons were made to the control group and any important increases or decreases that support the key findings will be discussed. When comparing questionnaires, 1 to 2 for the statement "I remember information from lessons really well" there was a 5.7 % increase in active group response. Furthermore, for the statement "I think having a good memory is important for learning" a 5.3% increase was seen in the active group response. For the statement "I think that having a good memory is part of being intelligent" an increase in the active group response of 4.7% was reported this increased to 16.1% when comparing questionnaire 1 to questionnaire 4. These data all indicate that the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. p. 236-244; Tables 21-28 p. 221-236)

When analysing the questionnaire responses to the statement "I think that having a good memory is important for learning." All the questionnaires throughout Year 7 and 8 show a positive difference in the active group compared to the control group. The positive difference in questionnaire 2 was 8.6% and the positive difference in the questionnaire 4 was 6.0%. This suggests that the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. 236- 244; Tables 21-28 p. 221-236)

Active students: "I think that having a good memory is part of being intelligent." At the end of Year 7 questionnaire 2 the positive comparative response has increased for the response "a bit" by 32.4%. This increases by a small amount in the first half of Year 8, by 1.5%. This indicates that during that time in the study the active students' perception of memory and intelligence was more positive than at the start of the end of the study. However, there was little comparative difference in response for the statements "I have a good memory" and "I am intelligent." This may indicate that WM activities are not influencing student cognition and hence, perception of their own memory or intelligence (Figures 27-33 p. 236-244; Tables 21-28 p. 221-236). This will mean that any conclusions made will have to be tentative in light of these findings.

5.5.2: The key quantitative findings linked to perception of learning in answering research question d.

The data from the student interviews responses to the question, whether the students found science easy, medium, or hard gave some interesting results. In Year 7, 18% of the control group found Science easy compared to 4% of the active group. Also, 0% of the control group reported finding Science hard, whereas, 8% of the active group said they found Science hard. There is a different pattern in Year 8 where we see the active group more polarised in their view with 12.8% saying Science was easy, 66% medium and 12.8% stating Science was difficult. The control group on the other hand still seem to be skewed towards easy; with 10.8% saying Science was easy, 86.5% saying Science was medium and only 2.7% reporting that they found Science difficult (Tables 23 & 26, p. 225 & 227).

The student interviews also shed light on the student's perception of what activities help them learn. In both Year 7 and 8 students reported that practical work helped them learn Science the most in Year 7, 38% of the active group, 44% of the control group. These figures are similar in Year 8 with a slightly lower 29.8% for the active group and 51.4% for the control group (Tables 21 & 24, p.221 & 225).

The second highest activity that helped students learn for both the control group and the active group were the activities to develop WM. In Year 7, 8% of the control group report using the reading sheets as helping them learn the most, this was even higher in the active group at 12 %. In Year 8, 16.2% of the control group report using the reading sheets as helping them learn the most this is even higher than the active group who reported 10.6%. In Year 7 and 8 the control group do not cite the listening activities as helping them learn the most. Whereas, the active group state the listening activities as helping them learn the most in Year 7 and 8, 12% and 10.6% respectively (Tables 21 & 24, p.221 & 225). This fits with the data from the lesson observations (p.243-245 and Appendix F) and the Science teacher questionnaires (p. 246-249 and Appendix F) show that the reading sheets in the control group lessons with more frequency as the study progressed. This evidence very tentatively suggests that the students' perception is second to practical activities, the activities to develop WM are helping them learn Science more that students in the control group.

The Year 7 & 8 Student Questionnaires were analysed for the students' perception of their learning. When doing comparisons of the questionnaire data the following findings became clear. The active group students' response to the statement "I am learning new information and skills" increased by 10.2% from questionnaire 1 to questionnaire 3 for the active group. Furthermore, the active students report being able to “I remember information from lessons well” in questionnaire 2 compared to questionnaire 1 with a positive difference of 6.8 % increasing to 15.1%. Hence this positive difference in the active group students’ perception of their learning increases in Year 7 and declines slightly in Year 8. This perception may be due to the exposure of the active group to the WM activities (Tables 27 & 28 p. 230 & 236, and Figures 27-35 p. 236-248).

5.5.3: The key qualitative findings linked to memory in answering research question d.

There are no key findings from the qualitative data specific to memory perception.

5.5.4: The key qualitative findings linked to learning in answering research question d.

The student interviews enabled students in the active group to explain why they found the memory activities useful for their learning. The responses were diverse and in Year 7, students commonly used the following words to explain why the activities were useful; remember, focus, science equipment, memory, useful, brain, learn. In Year 8 the responses were more diverse; remember, memory, reading sheets, other lessons, listen, learn, science and science equipment, focus, concentrate and brain. The majority of the responses were positive and the use of those specific words suggests that the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. 236-244 ; Tables 21-28 p. 221-236)

In response to the question about whether the students find Science easy, medium, or hard. The data indicates that proportionally the students in the active group found Science marginally more challenging (and good) and easier than the students in the control group. However, proportionally the control students stated they liked Science slightly more (see Tables 23 & 26, p.

225 & 227). This may indicate that the WM activities are changing the cognition of the active group students' which in turn is having an impact on their perspective on learning Science or could suggest that the WM activities might be having a polarising effect on students' perception. Or somehow the activities to develop WM are making Science easier or harder to learn depending on certain factors. However, as the distributions are very similar these are very tentative conclusions and would need other evidence to support them from the qualitative and quantitative data.

5.5.5: A discussion of the key findings from the quantitative and qualitative data integrated on answering research question d.

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science, with the possible outcome of a change to the students' perception of their memory and Science learning.

The overall key finding in answering research question d. is the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33, p. 236-244; Tables 21-28 p. 221-236) The first part of this section focuses on how the activities to develop WM had a positive impact on students' perception of learning in Science and the second part of the section focuses on, how the activities to develop WM had a positive impact on students' perception of their memory.

The three key constructs linked directly to RQ d. from the literature review are people who complete specific activities can increase their WM, increasing WM increases (Science) attainment and completing specific activities in the classroom can increase WM and hence increase (Science) attainment. The specific aspect of student perception of their memory and learning in Science will be the focus within these two key constructs in this section of the discussion.

Overall, the findings from the data tentatively indicate that the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. 236-244; Tables 21-28 p. 221-236) that is absent in the control group. One explanation for this is that the activities to develop WM have made it easier to learn due to changes in the students' cognition that were linked to WM, which were not picked up using the Lucid Recall WM assessment (St. Clair-Thompson, 2015).

There are no findings in the literature that specifically relate to WM training in Science improving students' perceptions of learning Science. However, there are findings in the literature that relate student perception of learning in mathematics (with some reference to reading comprehension). These are both aspects of Science lessons. Cornoldi, (2015) reported findings of increased mathematical problem solving after being exposed to a school-based WM and metacognition training intervention. The findings indicated that students' beliefs about mathematics became more positive. Overall, the WM part of the training had attributed to a greater extent to the increase in mathematical problem-solving ability than the metacognition part of the training (Cornoldi, Carretti, Drusi, & Tencati, 2015). This finding is consistent with that of Johann & Karbach, (2020) who report that students completing WM training have increased motivation compared to the control group (Johann & Karbach, 2020). In addition, Ashcraft & Krause, (2007) report that mathematics anxiety (a student's perception that they find mathematics difficult and this makes them anxious about doing mathematics) has a negative impact on WM and this leads to poor mathematics performance academically (Ashcraft & Krause, 2007).

An alternative explanation is that the activities to develop WM had an impact on the active group's cognition (which was not WM based) this made their perception of their memory and learning Science more positive compared to the control group. Wang & Liou, (2017) report the findings that motivational belief of "I do well in Science" had a significant relationship to Science attainment. Fleming et al, (2016) report similar findings that conscientiousness is linked to high academic attainment and some executive functions but not working memory (Fleming, Heintzelman, & Bartholow, 2016).

Finlayson, et al. (2014) reports findings that do not link mathematics anxiety (a negative perception of learning mathematics) to WM. Mathematics anxiety according to the Finlayson et al. study is thought to be caused by lack of self-confidence, fear of failure, teaching styles and ineffective learning practices. Suggestions were made following the research of what may help support students with mathematics anxiety. These strategies were for teachers to encourage risk taking, have opportunities to practice, go at a pace that suit the learning of the students, have a diverse range of teaching strategies and assessments (Finlayson, 2014). These reported strategies are in line with how the active group were delivered their lessons, however this is weak supporting evidence for this alternative explanation. This explanation is tentative because of the limited supportive findings in the literature.

Overall, the literature cited is in line with the findings of the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science; being conscientious and believing they do well in Science would in turn give a positive perception of their Science learning. These data need to be interpreted with caution as these are tentative links to the literature and there are no studies that directly investigate the impact of WM training on the perception of students’ learning Science and about their memory after WM.

The theoretical framework for this study (Figure 13) was developed using supporting literature to enable me to investigate the activities to develop WM at many levels rather than just a straightforward design using quantitative data. The use of questionnaires and interviews to gather data within the theoretical research framework (Figure 13), and specifically the inclusion of quantitative data have added a different dimension to the findings.

There are a number of education research studies that have used qualitative data from interviews and questionnaires to support their findings (e.g., Carretti, Re, & Arfe, 2013; Dignath &

Gerhard, 2008) and examples can also be found in Hattie's meta-analysis "*Visible Learning*" (Hattie, 2009). However, in WM studies the use of qualitative data is rare

and I have found no examples in the literature especially in relation to WM training and Science attainment. The student questionnaires and interviews from this study have enabled the outcome of this study to be investigated on different levels that would not have been revealed if the theoretical framework did not have the qualitative aspect. The theoretical framework (Figure 13) is a way to contibute to future theory and research.

Overall, the findings from the data tentatively indicates the activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33, p.236-244; Tables 21-28 p. 221-236)

5.6: A discussion of the quantitative and qualitative key findings in answering research question e. taking into full consideration the theory and findings from the literature review and the theoretical framework.

The key findings from the quantitative and qualitative data will be discussed in this section, in relation to research question e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions? The overall key finding in answering RQ e. is the activities to develop WM may have an impact on the cognition of the active group students, which may lead them to think metacognitively differently to the control group students (Figures 27-33, p. 236-244; Tables 22-28 p. 224-236)

The key findings from the quantitative and qualitative data will then be integrated and discussed taking into full consideration the theory and findings from the literature review and the theoretical framework. The two key constructs linked directly to RQ e. from the literature review are people who complete specific activities can increase their WM, increasing WM increases (Science) attainment and completing specific activities in the classroom can increase WM and hence increase (Science) attainment. The specific aspect of student metacognition will be the focus within these two key constructs in this this section of the discussion. Where metacognition is defined as students thinking about their thinking and learning.

5.6.1: The key quantitative findings in answering research question e.

In section 5.4 the findings discussed that in response to the student interviews the control group stated that they found Science easy. Whereas, the active group were polarised some stating it was difficult (challenging but good) and others stating it was easy. Both groups are demonstrating metacognition about their Science learning with differing outcomes. The active group's metacognition about their Science lesson is polarised whereas the control group find Science easier to learn (Tables 23 & 26, p. 225 & 227).

There is also a difference in the responses when the students were asked the metacognitive question "Which activities in Science help you learn the most?" Both groups favoured practical activities, but the active group had a smaller majority. A large percentage stated the activities to develop WM helped them to learn the most. The active groups' metacognition about the activities that helped them learn the most differed from that of the control group. However, both groups had a high percentage reporting that reading sheets helped them learn the most (Tables 21 & 24, p. 221 & 236, and Appendix E p. 429-451).

The data from the student questionnaires indicates that the active group have a higher percentage of students stating, "I remember information from lessons really well," "I think having a good memory is important for learning," "I think that having a good memory is part of being intelligent" and "I am learning new information and skills in Science (Tables 27 & 28 p. 230 & 236, and Figures 27-35, p. 236-248). These key findings can be seen in more detail in section 5.5. This suggests the activities to develop WM may have an impact on the cognition of the active group students, which may lead them to think metacognitively differently to the control group students (Figures 27-33, p.236-244, Tables 22-28 p. 230-236). Section 5.5 discusses the influence the activities to develop WM have on student perception.

5.6.2: The key qualitative findings in answering research question e.

The metacognition of the students is strongly indicated by the qualitative data. In both Year 7 and 8 the active group students had a diverse way of explaining why they found the memory activities useful. In Year 7 for example words used were; remember focus, science, equipment, memory, useful, brain and learn. In Year 8 for example words used were; remember, memory, reading sheets, other lessons, listen, learn, science and science equipment, focus, concentrate and brain (Tables 22 & 25, p. 224 & 227). However, the control students were not asked this question; this is a limitation of the study as there is no comparative data (this is discussed further in Section 5.7.2). Furthermore, the active group's teachers stated that they were using activities that would support the students with their memory, and sharing this explicitly with students would support the development of metacognition within the group (Table 73 p.456).

5.6.3: A discussion of the quantitative and qualitative key findings integrated on answering research question e.

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science, with a possible outcome of the study being, a change in students' metacognition.

In summary, the data indicates that the there is a difference in how the active group's students are thinking metacognitively compared to the control group's students. The active group students have a polarised view on how easy Science is to learn, and think practicals help their learning less than the control group. But both the control and the active group report the activities to develop WM, help their learning as their second highest activity. So, any conclusions drawn from this data must be very tentative.

Active group students have also demonstrated that they are thinking metacognitively with the various responses to the question. “Explain why the memory activities help you learn.” However, there was no comparative data from the control group. This is a limitation of this research study and will be discussed in Section 5.7.

The findings to answer RQ e. could be explained one of two ways. One explanation for the difference in metacognition between the active and control groups could be that the activities to develop WM have had an impact on the cognition that is linked to the WM of the active group, that could not be measured by the Lucid Recall WM assessment (St. Clair-Thompson, 2015). The activities to develop WM may have an impact on the cognition of the active group students that is linked to their WM, which may lead them to think metacognitively differently to the control group students. There is limited data, so this is a tentative explanation.

There is no literature that directly reports on WM training as an intervention to increase Science attainment and the impact on metacognition. There are findings from the literature that support WM and metacognition training being linked to increases in reading, listening and mathematics. These are all skills required in a Science classroom so are justified as findings to support this explanation albeit extremely tentatively. As stated in Section 5.5.5 Cornoldi, (2015) reported findings of increased mathematical problem solving after being exposed to a school-based WM and metacognition training programme (Cornoldi, Carretti, Drusi, & Tencati, 2015). The findings indicated metacognition improved, as did WM and mathematical problem-solving ability (Cornoldi, Carretti, Drusi, & Tencati, 2015).

Overall, the WM part of the training had attributed to a greater extent to the increase in mathematical problem-solving ability than the metacognition part of the training. However, the authors strongly suggest that metacognition is also positively influencing the attainment and recognizes this as an area where further study is needed. The improvements in mathematical problem-solving ability were also long lasting (Cornoldi, Carretti, Drusi, & Tencati, 2015). Furthermore, Carretti et al. (2014) report that metacognition training and WM training increase reading comprehension and increased metacognition was linked to increased listening comprehension (Carretti, Cardarola, Tencati, & Cornoldi, 2014),

An alternative explanation for the findings to answer RQ e. is the difference in metacognition between the active and control groups could be that the activities to develop WM may have no impact on the cognition linked with the WM of the active group students, but have had a positive influence on student cognition in a different way (e.g., other executive functions). The impact on the cognition of the active group caused the students to think differently metacognitively when compared to the control group. There is limited data, so this is a tentative explanation.

There are limited findings in the literature to support this explanation. Dignath and Gerhard, (2008) report that the teaching strategy of self-regulated learning uses metacognition to improve attainment in students (Dignath & Gerhard, 2008). Teng and Huang (2019) report the findings that English writing improved when metacognition strategies were used as part of self-regulated learning strategies. This established a link between metacognition and attainment (Teng & Huang, 2019). As there are limited findings to support this explanation in the literature, this tentative conclusion should be treated with caution.

The use of metacognitive quantitative data on to demonstrate the impact of an intervention was used in a small number of studies including Dignath and Gerhard, (2018) and Cornoldi et al. (2015) (Cornoldi, Carretti, Drusi, & Tencati, 2015; Dignath & Gerhard, 2008). This informed the design of my theoretical framework (Figure13). Overall, the findings would indicate the activities to develop WM may have an impact on the cognition of the active group students, which may lead them to think metacognitively differently to the control group students . Although due to a lack of comparative qualitative data this is a tentative conclusion. This may have contributed to the active group conditions reporting a positive influence on the Science knowledge and understanding. This is, however a very tentative conclusion.

5.7: Conclusion of the findings, limitations, and implications of the study

5.7.1 Conclusion of the findings

The goal of this doctoral study was to investigate the efficacy of a WM training intervention. The WM training intervention was embedded into the Science curriculum to address underachievement in Science. **What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?**

Which can be separated into five distinct questions.

a. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the working memory of the KS3 students (in Year 7 & 8) compared to the control conditions?

b. What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on science attainment of KS3 students (in Year 7 & 8) compared to the control conditions?

c. What are the far transfer effects on the KS3 students of the activities to develop working memory that I have developed for KS3 Science lessons compared to the control conditions?

d. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the KS3 students' perception of their memory, science?

and learning in Science compared to the control conditions?

e. What are the effects of the activities to develop working memory that I developed for KS3 Science lessons on the metacognition of KS3 Students compared to the control conditions?

Activities to develop WM have not made a significant difference to the active groups' post-test WM when compared to the control group (Table 11 & Table 12 p. 195 & 196) . This suggests that the activities to develop WM do not increase WM in KS3 students. This answers RQ a. However, in answering RQ b., there is no difference in terms of attainment (independent t-tests) but in the active group there are some conceptual links (correlation) in cognition between WM and students' knowledge and understanding of Science (this is seen in summative tests, chemistry homework and the end of Year 7 report grade).

Furthermore, the regression analysis between the post-test WM assessments and the end of Year 7 report grade suggests that WM has a 23.4% contribution to the end of Year 7 report grade. This lends some strength to the tentative finding that in early KS3 Secondary School Education (Year 7), WM intervention may be making conceptual links (correlation) of cognition between WM and students' knowledge and understanding of Science but not their Science investigative skills. The key findings tentatively suggest that the normal way of teaching may be having an impact on the cognition of control group students in their knowledge of Science investigative skills.(Independent t-test results Tables 101-106 in Appendix H p. 509-517 & Figure 27-29, p.236-238; Correlation test results Tables 107-115 in Appendix H p. 518-538 & Tables 13-17, p. 202-208, Tables 118-121 in Appendix H p. 547-556, & Figures 25-26 p.205; Dependent t-test results Tables 124-137 in Appendix H p. 561-580 & Tables 18-20 p. 212-218).

The activities to develop WM may have an impact on the cognition of the active group students that may lead to far transfer effects in other lessons (Figure 35, p. 248 & Tables 21 & 24, p.221 & 225) The quantitative data demonstrated an increase between the start and the end of the study of 4 to 16 students in the active group that were using the memory activities they practice in Science in other lessons. The qualitative data supported this finding; with a small number of 5 students across the two years, explicitly stating in interviews that the activities to develop WM had been useful in other lessons and or their everyday lives. The quantitative and qualitative data from the questionnaires and interviews has provided extra strata of understanding and support to these findings.

However, these findings are extremely tentative as there is no quantitative attainment data from other subjects to confirm the results of the student questionnaire. There is also no clear use of the term far transfer in the literature. So, far transfer has been used to show an increase in attainment in one subject after attainment in another subject (Adey & Shayer, 1993). However, in WM training it has been used to describe the skills practiced in the WM training intervention being used by the student in a subject area (Holmes & Gathercole, 2014) or if the WM training was specific a differing subject area (Diamond & Ling, 2016). These findings are also tentative and caution must be taken when interpreting these data as there is no literature that echoes a similar outcome in a similar setting; but especially not a secondary education Science setting with KS3 students. These are the findings that answer RQ c.

The activities to develop WM may have an impact on the cognition of the active group students that may lead to a shift in the perception of the students in the active group about their memory and learning (Figures 27-33 p. 236-244; Tables 21-28 p. 221-236). The quantitative and qualitative data findings from the student interviews and questionnaires tentatively demonstrates that the active group students had more positive responses to the questions about memory and learning in Science when compared to the control group. As far as I am aware there is no literature that is looking at the impact of WM training or interventions in schools on student's perception of their memory and their learning in Science. This has implications for the theory and future research of WM training in schools which will be discussed later on in this Section. This answers RQ d.

Finally, to answer RQ e. the findings would tentatively indicate that the activities to develop WM may have an impact on the cognition of the active group students, which may lead them to think metacognitively differently to the control group students (Figures 27-33, p.236-244 Tables 22-

28 p. 224-236). However, due to a lack of comparative qualitative data, and the small number of qualitative data responses , the data was interpreted with caution, this is a tentative conclusion.

In summary, to answer the overall research question; **What are the effects of the activities to develop working memory that I have developed for KS3 Science lessons on the WM and hence the science attainment of KS3 students?**

There was no difference between the active and control group's WM or Science attainment. However, the findings do indicate that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and the active student's knowledge and understanding of Science may also be related to changes in the active student's perception of memory, learning Science and metacognition.

These conceptual links (a correlation) in cognition between WM and students' knowledge and understanding of Science are present more in Year 7 active group students. This finding is supported by the regression analysis that suggests that WM is contributing to the end of Year 7 report grade by 23.4%. This may tentatively suggest that WM training intervention embedded in Science lessons is more effective in the Year 7 of KS3 Secondary Science.

Given that there are many non-significant differences between the means of the active and control group's Science attainment data. Also, the data tentatively suggests the control group condition may have an impact on the cognition of students in their knowledge of Science investigative skills In addition to the large number of non-significant correlations between the active group WM assessment and Science attainment; this is a tentative conclusion that should be treated with caution.

5.7.2 Limitations of the study

Conducting education research with a naturalistic experimental design framework by its' nature means conducting research within classrooms in a school. The lack of the tightly controlled laboratory conditions of alternative design frameworks leads to the introduction of numerous confounding variables that may impact on the research outcomes. This is something that I considered when designing the research study and led to me collating whole staff data, Science teacher and Science teaching assistant data so that the study could be as transparent as possible.

Ensuring that I was aware of how both the control and active groups' lessons were being implemented and if this cohort of students had any WM or memory input from other subject areas in the school that may skew the data. Lastly, being tentative about any conclusions drawn from the data due to the wide-ranging confounding variables that may also be impacting on the students in the research cohort.

Lucid Recall WM Assessment (St. Clair-Thompson, 2015) as the WM assessment test was a compromise. I completed extensive research to inform my choice of WM assessment test (Appendix B). However, I was constrained by budget and time to conduct the WM assessments. My preferred choice was the Automated Working Memory Assessment (Packiam Alloway, 2007), we had a teacher trained to administer the Automated Working Memory Assessment, but it was not available at the time and the school's licence for its' use had expired. My second choice would have been TOMAL 2 (Reynolds & Voress, 2007) but this was a test that was administered individually. I simply did not have the time or money to cover a teacher (or teachers) to test 182 students, both pre- and post-test. Although, Lucid Recall WM Assessment (St. Clair-Thompson, 2015) was standardised it has not been used in any research in the literature. This could indicate that the results from Lucid Recall are not rigorous, accurate, and precise enough to see differences in WM in the same student a few months apart. If I were to do this research again, I would use a shorter domain specific measure of WM such as a version of the n-back test.

The advantage of being a teacher at the school where the research was conducted & knowing the workings of the school intimately is a real strength. For example, in gaining easy access to the lesson observations and to be able to interview the students, deliver questionnaires to the students and staff. As well as, being able to work out the logistics and complete the WM assessment testing on 180 students with minimal impact to student learning in Science and other subjects.

On the other hand, I think that being a teacher at the school and being a well-known face in the school community was also a weakness of the research when collecting data from students to some extent but especially when collecting the data from Science teachers, teaching assistants and all the staff at the school. This could lead to participant bias of the data collected.

The questionnaires were usually delivered to student participants and staff in class or in staff meetings. This means that I had a captive audience so increased response rate but it may have compromised the accuracy or truthfulness of the answers given. Furthermore, the Science teaching staff, teaching assistant and whole staff questionnaires were not trialed in detail in a pilot study so there was not an opportunity to fine tune or modify the questionnaires or improve the quality of the questionnaires and hence the data derived from them. Finally, the gender was not recorded for any of the questionnaires so there might be a gender bias but I would not know it was present.

The other major limitation was caused by the confounding variable of the Worldwide Covid Pandemic. This meant that half way through the second year of my two-year research, students stopped being exposed to the WM activities to develop WM in the classroom. As students in the research cohort had to learn from home from March 2020 until the end of the academic. The strict guidelines brought in when students returned to school meant a post Year 8 WM assessment test was not possible on Lucid Recall at the start of Year 9 when students returned to the school site for their education. This is hugely disappointing, and has had an impact on available data and subsequent data analysis.

Another limiting factor for the quantitative Science assessment data is the change in the grading system at the research school between the action research study that inspired the PhD and this PhD study itself. When the government abolished the use of national curriculum levels and each secondary school was responsible for introducing its own summative attainment system for KS3, the grading system at the research school changed significantly. The research school's new grading system dovetailed the individual year group grades into the GCSE grades (if a student made the expected level of progress year on year). The year 7 grades were 7.1 to 7.9 and the year 8 grades were 8.1 to 8.9 (and so on).

The grade descriptors were new to the teaching staff and they may not have been confident awarding higher grades and erred on the side of caution when grading summative assessments, Science investigative skills assessments and Science homework. Although speculative, I believe it is worth considering as a limitation. This may have skewed the data.

In addition to which the end of year the report data was reported using the following bands: 7.1- 7.2, 7.3-7.4, 7.5-7.6, 7.7-7.8, 7.9 (this banding system was the same for Year 8 grades). Teaching staff with students who were between a 7.4 and 7.5 were advised to put them as a 7.3-7.4 (or 8.3-8.4 in Year 8). This was an SLT judgment, and despite trying to get the decision overturned both for the validity of the departmental data and PhD data; I was unsuccessful. This led to the year 7 and 8 end of year report grade data potentially being skewed to lower grades. These factors for recording year 7 and 8 grades for Science assessment may well have led to the data being recorded in a way that not only skewed the data towards lower grades but also condensed the data sets making statistically significant differences harder to demonstrate between the active and control group.

A further limitation was the lack of attainment data gathered from other subjects. This limits the strength of the conclusion for the findings for RQ c. relating to far transfer effects. These conclusions have had to be suggested tentatively as there is only the data from student questionnaires and student interviews to support the far transfer effects findings. Further research, should consider gathering data from all student's subjects in order to support any possible far transfer findings.

In this doctoral study the cohort of students was analysed as a whole active group and the whole control group. There were no additional subgroup data collected. This is a limitation as I was unable to see if there was a difference in WM, attainment, far transfer, perception, and metacognition for gender, SEND (EHCP) and any other subgroups.

Another limitation was the lack of a comparative question in the control group condition for the active group condition question "Explain why memory activities help you learn." The active group responses to support RQ e. were diverse and interesting in terms of metacognition. However, the control group did not have an equivalent question "Explain why the activities you do in Science help you learn" so any conclusion made from the qualitative findings to answer RQ e. must be extremely tentative and interpreted with caution.

Overall, the limitations of this study will inform any future research I conduct into WM training in a school setting.

5.7.3 Contributions of this study: An Introduction

This study was placed within a pragmatic paradigm. The pragmatic paradigm, epistemological stance of being neither realist nor constructivist embedded within the paradigm and having a naturalistic-experimental design framework; has enabled me to look beyond the straightforward quantitative answer to the research questions. The pragmatic paradigm enabled both quantitative and qualitative data to be collected. This allowed me to investigate the impact of the activities to develop WM on different levels. This led to a naturalistic experimental approach within a design framework utilising the Baddeley and Hitch model of WM.

5.7.4 Contributions of this study to the field of WM research theory

The aim of this study was to investigate the efficacy of a classroom-based WM training intervention I had developed. The aim being to investigate if the activities to develop WM, increased WM and hence increased Science attainment in KS3 students. Gaps were identified in the literature. There were no studies reporting findings on domain specific WM training in KS3 Science classrooms. There were few studies reporting findings on domain specific WM training intervention in classrooms. There even fewer studies where the WM training was embedded into the KS3 curriculum and delivered by teachers as part of standard lessons (Figures 1-3).

The broad contribution this study has made to WM research theory is an improvement in the understanding of the efficacy of a classroom based, domain specific WM training intervention on the attainment of secondary school aged students. Specifically, to follow on from that, this study has further contributed to WM research theory and is an improvement in the understanding of the efficacy of a Science specific classroom-based WM training intervention on the attainment of KS3 students. This type of study has not been previously been seen in the literature.

This study used both quantitative and qualitative data. The use of qualitative data to analyse the impact of domain specific WM training in secondary Science has not, as far as I am aware been seen in the literature before. The qualitative data contributes to a new perspective in WM training outcomes. This approach has begun to tentatively shed light on the impact of the WM training on students' perception of their learning and memory, their metacognition and far transfer effects. So, has tentatively, introduced a little more understanding of WM training on cognitive functions that have not previously been explicitly linked to the Baddeley and Hitch model (Baddeley & Hitch, 1974).

An example of a differing WM model that incorporates other cognitive functions implicitly is the Cowan model; the activated long term memory WM model. This is another WM model (where all the constructs are held under one umbrella term so cognitive functions that may not be included in WM are not excluded from the model). Although, there are similarities between the Baddeley and

Hitch model and the Cowan model there is conflicting evidence about how much overlap between the models does occur (Cowan, 2022). This is where the WM theory would benefit from further research, to build on the understanding of WM using models.

5.7.5 Contributions of the study to the field of WM research

The findings from this doctoral study add to the emerging literature regarding classroom-based activities to develop WM being implemented as an integral part of the KS3 Science curriculum and their potential to enhance Science attainment. The literature review (Chapter 2) demonstrated that there was a gap in the literature of domain specific WM training in secondary school Science. The theoretical framework (Figure 13) was designed to assist the investigation into the efficacy of intervention materials developed to train WM in a Science classroom. The Baddeley and Hitch (Baddeley & Hitch, 1974) model of WM was used within the theoretical framework, to demonstrate how learning new information is encoded into the LTM.

The theoretical framework required a WM model that was well supported in the literature and would support learning and support the theory that WM can be trained and improved. More recent research using neuroimaging has identified areas of the brain that change due to increases in WM after WM training in typically developing children (Jones, Adlam, Benattayallah, & Milton, 2022); however, this research is in its' infancy. So, currently there is still a need for WM models.

The Baddeley and Hitch model fulfils all these requirements, it is the most widely accepted model of WM in the literature (e.g., Alloway & Gathercole, 2009; Baddeley A. , 2001; Baddeley A. , 2014; Cowan, et al., 2005; Dehn, 2008; Engle R. , Tuholski, Laughlin, & Conway, 1999; Ericsson & Kinsch, 1995) and is widely used by other researchers studying WM in students in a school setting (e.g., Alloway & Gathercole, 2009; Fenesi, Sana, Kim, & Shore, 2015; Holmes & Gathercole, 2014; St Clair-Thompson, Stevens, Hunt, & Bolder, 2010).

The Baddeley and Hitch WM model's (Baddeley & Hitch, 1974) role within the theoretical framework can be seen in Figure 13. The literature supports the parts of this model; the visual-spatial sketch pad, the phonological loop, the episodic buffer, and the central executive can be clearly linked to learning in a (Science) class room (Fenesi, Sana, Kim, & Shore, 2015; Olive, Kellogg, & Piolat, 2008; Vanderberg & Swanson, 2007). Hence, WM is necessary for learning to take place (Cunningham & Sood, 2016; Dehn, 2008; Packiam Alloway & Alloway, 2015). New information taken in from listening (phonological loop), reading and practical activities (visual-spatial sketch pad) are processed and linked to memories in the LTM to form new memories. The episodic buffer enables some new information to be held without being lost during this process. This is supported in the literature and used within the theoretical framework of the study.

The advantage of the Baddeley and Hitch Model (Baddeley & Hitch, 1974) is that it has constructs that do not overlap with other areas of cognition or executive function. This means that WM can be measured without the impact of any potential intervention to improve the WM being diluted by also improving overlapping measures. This makes the Baddeley and Hitch Model useful but not necessarily truthful (this has been discussed in section 5.7.4).

The Baddeley and Hitch model of WM underpins the theoretical framework for this research (Figure 13). The theoretical framework is explained and justified in the Literature Review Chapter Two (section 2.11) of this dissertation. The tentative positive key findings of this research demonstrate the potential efficacy of using this theoretical framework for education research. This is a justification for other researchers with some refinement to use this theoretical framework as a starting point in their research (using a differing WM assessment and or WM model Sections 5.7.7-5.7.9 refer to this in more detail) in KS3 classrooms in a secondary school setting. Because the efficacy of this theoretical framework (albeit with tentative results), has been demonstrated to some extent in this study. This may allow researchers to generalise the outcomes of their research.

Consequently, this theoretical framework could be used as a starting point to enable research teams who currently research WM and learning in school aged students to move from the tightly laboratory based (and quantitative data focused) research to the naturalistic education research environment of the classroom. This would reap the benefits of having classroom evidence-based research that is more consumable and repeatable by teachers delivering the Science curriculum. This theoretical framework also, demonstrates that naturalistic experimental research in the classroom can shine a spotlight on previously unseen phenomena in WM research including the findings from this study. These indicate that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and the active student's knowledge and understanding of Science may also be related to changes in the active student's perception of memory, learning Science, metacognition and possibly far transfer of skills to other subjects.

5.7.6 Contributions of the study to the field of Pedagogy, Teaching & Learning

The analysis and synthesis of the research into WM and WM training was used to design and further fortify the development of a Science specific WM training intervention. This Science specific WM training intervention is supported by theory and can be used in secondary school Science classrooms. Hence, with the Science specific activities to develop WM, this study contributes to the field of classroom WM intervention development.

Gaps have been identified in the WM training literature. There has as far as I am aware, been no literature published on Science specific WM training in KS3 Science classrooms with the aim of increasing Science attainment. This study has demonstrated through its findings that the Science specific WM training is not an effective tool to increase WM with Lucid Recall WM Assessment (St. Clair-Thompson, 2015). However, the Science specific WM training experienced by the active group students may have resulted in some conceptual links (a correlation) in cognition between WM and the active students' knowledge & understanding of Science.

This seems to tentatively indicate that the findings of this study could contribute to teaching and learning strategies for activities to develop WM. This specific contribution may have an impact on conceptual links (a correlation) in cognition between WM and the active students' knowledge & understanding of Science; this cautiously suggests that they will have a positive impact on the cognition of the active group students. However, as stated earlier this is a tentative contribution due to the non-significant findings in relation to the impact the activities to develop WM had on WM and Science attainment. Specifically, the WM of both the active and control groups both increased. But there was no significant difference between the post-test mean of the control group compared to the active group. This is addressed in more detail in Sections 5.7.2 and 5.7.10.

5.7.7 Implications of the study for WM research theory

The literature has strongly suggested that domain specific classroom-based interventions of WM training may have an impact on student attainment. This doctoral study's findings are not in line with the literature, due to the lack of a significant increase in WM or attainment in the active group. However, the data does suggest that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science.

All the WM models support the idea that WM is required for learning to take place. An alternative view is that the model of WM that was being used and tested by Lucid Recall WM assessment in this study, is not an effective model to use for learning in a KS3 Science classroom. The findings of this study tentatively suggest, that the theory of WM should consider that alternative WM mechanisms may be at play physically in a students' WM that are not represented by the Baddeley and Hitch Model of WM.

However, domination of the Baddeley and Hitch model has coincided with a dearth of WM training research with contradictory findings .The possibility that other cognitive constructs are involved with WM but are not yet fully understood or explored by the researchers is acknowledged in Cowan's activated long term memory model of WM (Cowan, 2022). This is on reflection, perhaps a better model to use in a theoretical framework for classroom-based research. The findings from this study support the need for alternative WM theories to be used more in WM training research theoretical frameworks. This would provide much needed findings to support or refute the differing models. This would contribute to the field of WM theory.

The absence of consistent evidence for school or classroom-based WM training interventions increasing WM and having near and far transfer effects has been at the core of the WM training debate. When conducting research, it is important that the researchers of WM training provide a theoretical explanation for near and far transfer. However, these models of WM must be treated with caution (they are useful but potentially not truthful) there is much still to find out about the cognition of WM function (Shipstead, Redick, & Engle, 2012)

Fenesi et al., (2015) comment on the merit of other WM models, but also on those models being harder to use as they have overlapping constructs with other cognitive functions, the efficacy of any WM training is then difficult to test, and the recommendation is to use the Baddeley and Hitch model in education research (Fenesi, Sana, Kim, & Shore, 2015). The attention focus long term memory WM model is supported by or has been commented on having merit by some researchers (e.g., Anderson, 1990; Cowan, 2014; Fenesi, et al., 2015; Engle, et al., 1999; Oberauer, et al., 2000; Tehan, et al., 2001) as has the embedded focus model (Ericsson & Kinsch, 1995). It is however, the Baddelely and Hitch model (Baddeley & Hitch, 1974) that dominates the WM training research for the reasons outlined above. The findings from this study suggest that using the Baddeley and Hitch model in a WM training theoretical framework should be treated with caution and other models of WM be considered (this is explored further in Section 5.7.8 & Section 5.7.10).

5.7.8 Implications of the study for research into WM training

The Baddeley and Hitch model (Baddeley & Hitch, 1974) dominates the WM training research. It is the model that is predominantly used within the theoretical framework of researchers in this field. The Baddeley and Hitch model (Figure 4) has distinct non-overlapping components. The components of the Baddeley and Hitch model of WM do not overlap with other cognitive functions such as executive function. This means it is easy and less complex to interpret results using this model.

There are other WM models that are not used as much in WM training research due to the reasons outlined earlier in section 5.7. The findings of previous studies investigating the efficacy of WM training in school settings are inconsistent and in some instances contradictory (as discussed in Section 5.4.3). Where for example the efficacy of training ranged from improving WM with no transfer effects (Himi, Stadler, von Bastian, Bühner, & Hilbert, 2022), to near transfer effects (Peng & Swanson, The domain-specific approach of working memory training, 2022) and far transfer effects (Blair & Raver, 2014).

The naturalistic experimental design of this research conducted within the theoretical framework outlined (Figure 13) and justified in Chapter Two (Section 2.11) of this dissertation has demonstrated tentative positive outcomes to my research questions. The theoretical framework is embedded within a secondary Science education context. The justification of the theoretical assumptions has enabled the theoretical framework to act as a vehicle. This has facilitated the theoretical framework to demonstrate the efficacy of using activities to develop WM in the classroom. The findings indicating that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and the active student’s knowledge and understanding of Science may also be related to changes in the active student’s perception of memory, learning Science, metacognition and may have a far transfer effect of practiced skills.

These findings provide some tentative initial evidence that the theoretical framework (Figure 13) may be effective in being able to affect some conceptual links (a correlation) in cognition between WM and the students' knowledge and understanding of Science. If other researchers use this theoretical framework as a starting point in their research, then their findings may well be consistent with mine. Or they may go on to have more significant findings than mine. This could have implications for WM training research in a school setting both nationally and internationally.

5.7.9 Implications of the study to pedagogy, teaching and learning strategies

The findings from this study tentatively suggest that there may be merit in conducting Science specific WM training interventions in a classroom setting. However, the large number of non-significant findings cast some doubt on the efficacy of WM training to improve WM and hence, Science attainment for all KS3 secondary school students. But my study did not examine the data of the participant cohort's subgroups. The findings in the literature support WM training having the biggest impact on students with lower WM (Dunning, Holmes, & Gathercole, 2013; Spencer-Smith, et al., 2020). There still maybe merit in exploring further the usefulness of domain specific WM training for certain subgroups of students.

Political leaders and other decision makers in the education sector, should reflect on the pedagogical and cost effectiveness of whole class WM training interventions. Whole class WM training intervention may lead to the overall effect being smaller as some specific subgroups are benefitting more than others (e.g., the students with low WM or ECHP or PP students) in a mainstream classroom.

There are WM researchers such as Cowan advising that caution should be exercised when using activities to develop WM in the classroom due to there being conflicting evidence in a field where is it is difficult to conduct the research (Cowan, 2022). However, although some researchers find the concept of WM training controversial there is an argument that it could benefit certain groups of individuals and may result in near or far transfer effects (Alloway & Gathercole, 2009).

Intervention with targeted groups of students on a regular basis may lead to a greater training effect and transfer effect. Further research is required in this area to provide more clarity on the efficacy of Science specific WM training in a classroom setting (section 5.7.10).

The findings from this study may help us to understand the role of WM in learning Science. The findings indicate that tertiary education policy makers and senior leaders across the education sector should work together to ensure good training opportunities are available on WM and its' role in learning (Science). Headteachers, teachers and teaching assistants should have training in WM (during initial teacher and teaching assistant training courses and throughout their careers in education). This training should specifically include, how WM links to learning, with particular attention paid to the impact of low WM on student attainment and the overlap between specific SEND learning disabilities and low WM (Alloway, 2009).

The findings from this study cautiously support the use of teaching and learning strategies where teachers can make small domain specific changes to the activities, they deploy in the classroom to tax the WM (e.g., listening, reading, and writing activities).

The findings tentatively suggest that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and the active student's knowledge and understanding of Science may also be related to changes in the active student's perception of memory, learning Science, metacognition and possibly a far transfer effect. These activities are easy to implement, cost effective and not time consuming to produce and may be used as one of a combination of strategies to tackle underachievement in Science and potentially other subjects.

5.7.10 Suggestions for further research & next steps

This research has shone a spotlight on the efficacy of conducting an WM training intervention embedded within the Science curriculum in KS3 Science classrooms. The activities to develop WM were embedded into the KS3 Science curriculum with the intention of improving WM and hence Science attainment. The key findings tentatively indicate that the active group students have some conceptual links (a correlation) in cognition between WM and the students' knowledge & understanding of Science. These conceptual links (a correlation) in cognition between WM and the active student's knowledge and understanding of Science may also be related to changes in the active student's perception of memory, learning Science, metacognition and maybe far transfer effects. These findings should be treated with caution due to the number of non-significant findings.

The findings from this study have raised key issues in three areas; WM theory, WM research and use of WM training in the classroom. WM theory which was discussed earlier has been dominated by the Baddeley and Hitch model of WM (Baddeley & Hitch, 1974) particularly in the area of WM training. The findings from this study suggest that further research using the theoretical framework (Figure 13) as a starting point but using differing WM models and different ways of conducting pre-test and post-test WM assessment would provide evidence to begin to clarify the role of cognitive constructs within WM. This would need many studies with the different permutations of WM model and WM assessment. The findings from such studies would be more reliable and more robust if they had an active control group (that had a similar adaptive intervention).

The findings from such research would add to our understanding of the models of WM and their connectedness to the action of learning in the classroom. The attainment data of all subjects in the school should be gathered and analysed to investigate the presence of far transfer effects. This would contribute further to the theory of WM.

A report evaluating the impact of pupil premium states pathway to success as: " have an individualised approach to addressing barriers to learning, ...high quality teaching … and develop the skills and knowledge of teaching staff and TAs working with the pupils" (Macleod, Sharp, Danielle, Skipp, & Higgins, 2015, p. 10). An intervention that incorporates these recommendations is the introduction of a domain specific working memory training intervention embedded within a curriculum. Titz and Karbach (2014) report in a review the findings that domain specific WM training can have positive effects on academic performance (especially those linked with reading) and seems to be of particular benefit to low achieving pupils (Titz and Karbach, 2014).

The findings from this study were limited by the fact that they only analysed the data as an entire cohort. Further research comparing subgroups of students (e.g., gender, SEND, EHCP, weak WM, PP) using the theoretical framework and a more reliable WM assessment would provide valuable data to further determine the efficacy of the Science specific activities to develop WM and hence Science attainment.

The role of WM in learning is well supported in the literature (e.g.,Bardack, Lopez, Levesque, Chigeda, & Winiko, 2023; Berkowitz, Edelsbrunner, & Stern, 2022; Cowan, 2022; Kim & Kasari, 2023) and as part of my new job role I will be conducting CPD training with teachers and support workers on WM, its' role in learning, how to adapt teaching and learning strategies and resources for students with weaker WM, and how to incorporate domain specific activites to develop WM into the curriculum. The aim of this CPD is to increase teacher awareness of the importance of WM in learning and give them teaching and learning strategies that will support the appropriate level of cognitive load for students to learn (Cowan, 2022). This should be impactful for student attainment. These strategies are cost-effecitve and have the impact of supporting students with weaker WM and supporting the development of WM to encourage an increase in attainment. My hope is that this will increase student's life chances. This is the reason I became a Science teacher and is the reason why teaching still brings me so much joy.

References

14-19 Learning & Skills Bulletin. (2019, December 11). Attainment gap between disadvantaged pupils and their peers bigger than previously thought. *14-19 Learning & Skills Bulletin, 317*, pp. 12-13.

Abadzi, H. (2016). Training 21st-century workers: Facts, fiction and memory illusions. *Internation Review of Education, 62*, 253-278.

Ackerman, P. L., & Boyle, M. O. (2005). Working Memory and Intelligence: The Same or Different Constructs? *Psychological Bulletin, 131*(1), 30-60.

Ackerman, P. L., Beier, M. E., & O'Boyle, M. (2005). Working Memory and Intelligence: The Same or Different Constructs? *Psychological Bulletin, 131*(1), 30-60.

Adesope, O. O., Trevisan, D. A., & Sundararajan, N. (2017, June). Rethinking the Use of Tests: A Meta-Analysis of Practice Testing. *Review of Educational Research, 87*(3), 659–701.

Adey, P., & Shayer, M. (1993). An Exploration of Long-Term Far-Transfer Effects Following An Extended Intervention Program in the High School Curriculum. *Cognition and Instruction, 11*(1), 1-29.

Affes, S., Borji, R., Zarrouk, N., Sahli, S., & Rebai, H. (2021). Effects of running exercises on reaction time and working memory in individuals with intellectual disability. *Journal of Intellectual Disability Research*, 91-112.

Alivernini, F., & Manganelli, S. (2015, July 1). Country, School and Students Factors Associated with Extreme Levels of Science Literacy Across 25 Countries. *International Journal of Science Education, 37*(12), 1992–2012.

Alloway, T. (2009). Working Memory is the Key to Learning. *Teaching, Thinking and Creativity, 9:3*, 10-13.

Alloway, T. (2009). Working Memory is the Key to Learning. *Teaching, Thinking and Creativity, 9:3*, 10-13.

Alloway, T. P., & Gathercole, S. E. (2009). *Working Memory and Learning: A Practical Guide for Teachers.* London: SAGE Publications.

Anderson, J. R. (1990). *Cognitive Psychology and its' Implications.* New York: W H Freeman and Company.

Andrade, J. (2001). *Working Memory in Perspective.* (J. Andrade, Ed.) Hove, East Sussex, England: Psychology Press Ltd.

Ansari, D., & De Smedt B: Grabner, R. (2012). Neuroeducation – A Critical Overview of An Emerging Field. *Neuroethics, 5*, 105-117.

Apter, B. J. (2012). Do computerised training programmes designed to improve. *Educational Psychology in Practice, 28*(3), 257-272.

Aries, R. J., Groot, W., & van den Brink, H. M. (2015). Improving reasoning skills in secondary. *British Educational Research Journal, 41*(2), 210–228.

Aries, R. J., Groot, W., & van den Brink, H. M. (2015). Improving reasoning skills in secondary history education by working memory training. *British Educational Research Journal, 41*(2), 210–228.

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance and math anxiety. *Psychonomic Bulletin and Review, 14*(2), 243-248.

Au, J., Buschkuehl, M., Duncan, G. J., & Jaeggi, S. M. (2016). There is no convincing evidence that working memory training is NOT effective: A reply to Melby-Lervag and Hulme(2015). *Psychonomic Bulletin and Review, 23*, 331-337.

Au, J., Sheehan, E., Tsai, N., Duncan, G. J., Buschkuehl, M., & Jaeggi, S. M. (2015). Improving fluid intelligence with training on working memory: a meta-analysis. *Psychonomic Bulletin and Review, 22*, 366-377.

Baars, S., Shaw, B., Mulcahy, E., & Menzies, L. (2019, May 15). *School cultures and practices: supporting the attainment of disadvantaged pupils A qualitative comparison of London and non-London schools.* Retrieved from Deparment for Education: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/730628/London_Effect_Qual_Research_-_Research_Report_FINAL_v2.pdf

Baddeley, A. (1986). *Working Memory.* Oxford: Oxford University Press.

Baddeley, A. (2001, November). Is Working Memory Still Working? *American Psychologist*, 851-864.

Baddeley, A. (2014). *Essential Of Human Memory* (Classic ed.). East Sussex, England: Psychology Press.

Baddeley, A. (2014). *Essential Of Human Memory* (Classic ed.). Hove , East Sussex, England: Psychology Press.

Baddeley, A. (2014). *Essentials Of Human Memory* (Classic ed.). East Sussex, England: Psychology Press.

Baddeley, A. (2014). *Essentials Of Human Memory* (Classic ed.). Hove, East Sussex, England: Psychology Press.

Baddeley, A. D. (2001, November). Is Working Memory Still Working? *American Psychologist*, 851-864.

Baddeley, A. D., & Hitch, G. (1974). In G. H. Bower, & G. H. Bower (Ed.). London: Academic Press.

Banerjee, P. A. (2016). A systematic review of factors linked to poor academic performance of disadvantaged students in science and maths in schools. *Cogent Education, 3*(1), 1-17.

Banks, J. B., Wellhaf, M. S., & Srour, A. (2015). The protective effects of brief mindfulness meditation training. *Consciousness and Cognition*, 277-285.

Bardack, S., Lopez, C., Levesque, K., Chigeda, A., & Winiko, S. (2023, February 23). An exploratory analysis of divergent patterns in reading progression during a tablet-based literacy program. *Frontiers in Education*, 1-9.

Barenberg, J., Roeder, U., & Dutke, S. (2018). 'Students' temporal distributing of learning activities in psychology courses: factors of influence and effects on the metacognitive learning outcome. *Psychology Learning and Teaching*, 257-271.

Barrow, R., & Woods, R. (2006). *An Introduction to Philosophy of Education* (4th ed.). Abingdon, Oxon, England: Routledge.

Bedford, S. (2017). Growth mindset and motivation: a study into secondary school science learning. *Research Papers in Education*, 424-443.

Benjamin, A., & Tullis, J. (2010, November). What makes distributed practice effective? *Cognitive Psychology, 61*(3), 228-247.

Berkowitz, M., Edelsbrunner, P., & Stern, E. (2022). The relation between working memory and mathematics performance among students in math-intensive STEM programs. *Intelligence, 92*, 1-12.

Berninger, V. W., Abbott, R. D., Swanson, H. L., Lovitt, D., Trivedi, P., Lin, S.-J. (., . . . Amtmann, D. (2010). Relationship of Word- and Sentence- Level Working Memory to Reading and Writing in Second, Fourth, and Sixth Grade. *Language, Speech, and Hearing Services in Schools, 41*, 179-193.

Bierman, K. L., Nix, R. L., Greenberg, M. T., Blair, C., & Domitrovich, C. E. (2008). Executive functions and school readiness intervention: Impact, moderation, and mediation in the Head Start REDI program. *Development and Psychopathology, 20*, 821-843.

Black, P., & Wiliam, D. (1998). *Inside The Black Box: Raising Standards Through Classroom Assessment.* Cambridge: King's College London, School of Education. nferNelson.

Blaikie, N. W., & Priest, J. (2017). *Social research: paradigms in action.* Cambridge: Polity Press.

Blair, C., & Raver, C. (2014). Closing the Achievement Gap through Modification of Neurocognitive and Neuroendocrine Function: Results from a Cluster Randomized Controlled Trial of an Innovative Approach to the Education of Children in Kindergarten. *PLOSone, 9*(11), 1-13.

Boudreau, D., & Contanza-Smith, A. (2011). Assessment and Treatment of Working Memory Deficits in School Age Children: The Role of the Speech and Language Pathologist. *Language, speech and hearing sevices in Schools, 42*, 152-166.

Brian, R. R. (n.d.).

Broadbent, D. E. (1958). *Perception and Communication.* Oxford: Pergemon Press.

Bruer, J. T. (1997, November). Education and the Brain: A Bridge Too Far. *Educational Researcher, 26*(8), 4-16.

Bryan, R. R., Glynn, S. M., & Kittleson, J. M. (2011, July 25). Motivation, Achievement, and Advanced Placement Intent of High School Students Learning Science. *Science Education*, 1049-1065.

Burrell, G., & Morgan, G. (2016). *Sociological Paradigms and Organisational Analysis: Elements of the sociology of corporate life.* Abingdon: Routledge. Retrieved 1 2018, 22, from http://reader.vlebooks.com/reader/open?accId=10344&bookmark=0&cite=0&isbn=9781351899154&maxCopy=0&maxPrint=0&mmLimit=5&notes=0&pageLimit=50&shareLink=&startPage=1&timestamp=2018-01-22T20%3A07%3A41&userId=690202&watermark=++++++++++++++++++++++++++++++%2F+

Buschkuehl, M., Jaeggi, S. M., Hutchinson, S., Perrig-Chiello, P., Dapp, C., Muller, M., . . . Perrig, W. J. (2008). Impact of Working Memory Training on Memory Performance in Old-Old Adults. *Psychology and Aging, 23*(4), 743-753.

Carden, J., & Cline, T. (2015). Problem solving in mathematics: the significance of visualisation. *Educational Psychology in Practice, 31*(3), 235–246.

Carr, D. (2010). *Making Sense of Education: An Introduction to the Philosophy and Theory of Education and Teaching.* Abingdon, Oxon, England: Routledge.

Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training. *British Journal of Educational Psychology, 84*, 194-210.

Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. . *British Journal of Educational Psychology, 84*, 194-210.

Carretti, B., Re, A. M., & Arfe, B. (2013). Reading Comprehension and Expressive Writing: A comparison between good and poor comprehenders. *Journal of Learning Disabilities, 46*(1), 81-96.

Cartwright, N. (2007). Are RCTs the gold standard? *Biosocieties, 2*(1), 11-20.

Chambers, R., Chuen Yee Lo, B., & Allen, N. B. (2008). The Impact of Intensive Mindfulness Traning on Attentional Control, Cognitive Style and Affect. *Cognitive Therapy Reaseach, 32*, 303-322.

Chi, M. T. (1978). Knowledge Structures and Memory Development. In R. Siegler, & R. Siegler (Ed.), *Children's Thinking What Develops?* (pp. 73-96). Hillsdale: Lawrence Erbaum Associates Publishers.

Cline, A. (2017, March 7). *What is Epistemology?* Retrieved June 20, 2017, from ThoughtCo: https://www.thoughtco.com/what-is-epistemology-250526

Cohen, L. (2017). *Research Methods in Education.* Milton: Routledge.

Cohen, L. (2017). Surveys, Longitudinal, Cross-Sectional and Trend Studies. In L. Cohen, *Research Methods in Education* (8th ed., pp. 334-360). Milton: Routledge.

Cohen, L., & Manion, L. (1994). *Research Methods in Education* (4th ed.). London, England: Routledge.

Cooper, S. J. (2005). Donald O. Hebb's synapse and learning rule: a history and commentary. *Neuroscience and Biobehavioural Reviews, 28*, 851-874.

Copeland, J. (2019). A critical reflection on the reasoning behind, and effectiveness of, the application of the Pupil Premium Grant within primary schools. *Management in Education, 33*(2), 70-76.

Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. *British Journal of Educational Psychology, 85*, 424-439.

Cowan, N. (1988). Evolving Conceptions of Memory Storage, Selective Attention, and Their Mutual Constraints Within the Human Information-Processing System. *Psychological Bulletin, 104*(2), 163-191.

Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Education Psychology Review, 26*, 197-223.

Cowan, N. (2022). Working memory development: A 50-year assessment of research and underlying theories. *Cognition, 224*, 1-19.

Cowan, N., Elliott, E. M., Saults, S. J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capcity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*, 42-100.

Craik, F. I., & Watkins, M. J. (1973). The Role of Rehearsal in Short Term Memory. *Journal of Verbal Learning and Verbal Behavior, 12*, 599-607.

Creswell, J. W., & Garrett, A. L. (2008). The movement of mixed methods research and ther role of educators. *South African Journal of Education*, 321-333.

Creswell, J. W., Shope, R., Plano Clark, V. L., & Green, D. O. (2006). How interpretive qualitative extends mixed methods research. *Research in the Schools, 13*(1), 1-11.

Cromley, J. G., Weisburg, S. M., Dai, T., Newcombe, N. S., Schunn, C. D., Massey, C., & Merlino, F. J. (2016, July 5). Improving Middle School Science Reasoning Using Diagrammatic Reasoning. *Science Education, 100*(6), 1184-1213.

Cunningham, J., & Sood, K. (2016). How effective are working memory training interventions at improving maths in schools: a study into the efficacy of working memory training in children aged 9 and 10 in a junior school? *Education 3-13*, 1-14.

Daneman, M., & Carpenter, P. A. (1980). Individual Differences in Working Memory and Reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.

Daneman, M., & Merickle, P. (1996). Working Memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review, 3*(4), 422-433.

Day, J. J., & Sweatt, J. D. (2011). Cognitive neuroepigenetics: A role for epigenetic mechanisms in learning and memory. *Neurobiology of Learning and Memory, 96*, 2-12.

Dehn, M. J. (2008). *Working Memory and Academic Learning: Assessment and Intervention.* New Jersey: John Wiley & Sons Inc.

Delamont, S. (2017). Ethnography. In D. Wyse, *The BERA/SAGE Handbook of Educational Research: Two Volume Set* (pp. 336-354). London: SAGE Publications LTD.

Demetriou, A., Spanoudis, G., Shayer, M., van der Van, S., Brydges, C. R., Kroesbergen, E., . . . Swanson, H. L. (2014). Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modelling of 14 studies. *Intelligence, 46*, 107-121.

DfE. (2015, May 8). *2010 to 2015 government policy: education of disadvantaged children*. Retrieved December 6, 2015, from gov.uk: 2010 to 2015 government policy: education of disadvantaged children

Diamond, A. (2010). The Evidence Base for Improving School Outcomes by Addressing the Whole Child and Addressing Skills and Attitude, Not just content. *Early Education and Development*, 780-795.

Diamond, A. (2011). Activities and Programs that improve Children's Executive Functions. *Current Directions in Psychological Science, 21*(5), 335-341.

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches forimproving executive functions that appear justified and those that,despite much hype,do not. *Developmental Cognitive Science, 18*, 34-48.

Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264.

Dobbs, D. (2007). Erik Kandel: From Mind to Brain and Back Again. *Scientific American Mind, 18*(5), 32-37.

Dougherty, M. R., & Robey, A. (2018). Neuroscience and Education: A Bridge Astray. *Current Directions in Psychological Science, 27*(6), 401-406.

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12 - year old children. *Psychological Test and Assessment Modelling, 52*(4), 419-431.

Dudovskiy, D. (n.d.). *Epistemology*. Retrieved 6 22, 2017, from Research Methodogy: http://research-methodology.net/research-philosophy/epistomology/

Duemer, L. S., & Zebidi, A. (2009). The Pragmatic Paradigm: An Epistemological Framework for Mixed Methods Research. *Journal of Philosophy and History of Educator, 59*, 163-168.

Duncan, L. G., McGeown, S. P., Griffiths, Y. M., Stothard, S. E., & Dobai, A. (2016). Adolescent reading skill and engagement with traditional and digital literacies as predictors of reading comprehension. *British Journal of Psychology, 107*, 209-238.

Dunning, D. L., Holmes, J., & Gathercole, S. E. (2013). Does working memory training lead to generalized improvements in children with low working memory? A randomized control trial. *Developmental Science, 16*(6), 915-925.

Education Endowment Foundation. (2019, December 29). *Science*. Retrieved December 29, 2019, from Education Endowment Foundation: https://educationendowmentfoundation.org.uk/school-themes/science/

EEF. (2019, February 20). *Teaching and Learning Toolkit: An Accessible Summary of the International Evidence for Teaching 5-16 year olds*. Retrieved from Education Endowment Foundation: https://educationendowmentfoundation.org.uk/evidence-summaries/teaching-learning-toolkit

Engle, R. D., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309-331.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent-Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309-331.

Engle, R., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent-Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309-331.

Engle, R., Tuholski, S., Laughlin, J., & Conway, A. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309-331.

Englund, J. A., Decker, S. L., Woodlief, D. T., & DiStefano, C. (2014). Developemnt and Evaluation of an Online, Multicomponent Working Memory Batter. *Assessment, 21*(5), 543-561. doi:10.1177/1073191114524016

Ericsson, A. K., Delaney, P. F., Weaver, G., & Mahadevan, R. (2004). Uncovering the structure of a memorist's superior "basic" memory capacity. *Cognitive Psychology, 49*, 191-237.

Ericsson, K. A., & Kinsch, W. (1995). Long-Term Working Memory. *Psychological Review, 102*(2), 211-245.

Eriksson, J., Vogel, E. K., Lansner, A., Bergstrom, F., & Nyberg, L. (2015, October 7). Neurocognitive architecture of working memory. *Neuron, 88*(1), 33-46.

Farina, M. (2017). Neural Plasticity: Don't Fall For All The Hype. *British Academy Review*, 54-56.

Faust, M. W., Ashcraft, M. H., & Fleck, D. E. (1996). Mathematics Anxiety Effects In Simple and Complex Addition. *Mathematical Cognition, 2*(1), 25-47.

Feilzer, M. Y. (2010). Doing Mixed Methods Research Pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research, 4*(1), 6-16.

Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualsing Working Memory in Educational Research. *Education Psychology Review, 27*, 333-351.

Fernandez-Molina, M., Trella, M., & Barros, B. (2015). Experiences with tasks supported by a cognitive e-learning system in preschool: Modelling and training on working memory and attentional control. *International Journal of Human Computer Studies, 75*, 35-51.

Finlayson, M. (2014). Addressing math anxiety in the classroom. *Improving Schools, 17*(1), 99-115.

Fiorello, P. (2020, April 29). *Top Rated Education Systems With K12 Reviews*. Retrieved April 29, 202, from Critical Issues In Education: https://drpfconsults.com/top-rated-education-systems-k12-reviews/

Flanagan, C. (2012). *Research Methods Companion for A Level Psychology.* Oxford, Oxfordshire, England: Oxford University Press.

Flavell, J. H., Beach, D. R., & Chinksy, J. M. (1966). Spontaneous Verbal Rehearsal in a Memory Task As A Function of Age. *Child Psychology, 37*, 283-289.

Fleming, K. A., Heintzelman, S. J., & Bartholow, B. D. (2016, June). Specifying Associations Between Conscientiousness and Executive Function: Mental Set Shifting, Not Prepotent Response Inhibition or Working Memory Updating. *Journal of Personality, 84*(3), 348-359.

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2015). Shortened complex span tasks can reliably measure working memory capacity. *Memory and Cognition, 43*, 226-236. doi:10.3758/s13421-014-0461-7

Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not All Executive Functions Are Related to Intelligence. *Psychological Science, 17*(2), 172-179.

Garrity, L. I. (1975). An Electromyographical Study of Subvocal Speech and Recall in Preschool Children. *Developmental Psychology, 11*(3), 274-281.

Gathercole, S. E. (2001). Phonological short-term memory contributes to sentence processing in young children. (S. E. Gathercole, Ed.) *Memory, 9*(4,5 and 6), 349-363.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working Memory Skills and Educational Attainment: Evidence from National Curriculum Assessments at 7 and 14 Years of Age. *Applied Cognitive Psychology, 18*, 1-16.

Giedd, J. N. (2015, June). The Amazing Teen Brain. *Scientific American*, pp. 20-25.

Giofre, D., & Mammarella, I. C. (2014). The relationship between working memory and intelligence in children: Is the scoring procedure important? *Intelligence, 46*, 300-310.

Giofre, D., Mammarella, I. C., & Cornoldi, C. (2014). The relationship among geometry, working memory, and intelligence in children. *Journal of Experimental Child Psychology, 123*, 112-128.

Glaserfeld, E. (1984). *www.univie.ac.at/constructivism/EvG/papers/070.1.pdf.* Retrieved September 19, 2017, from /www.univie.ac.at/constructivism/EvG/papers/070.1.pdf: http://www.univie.ac.at/constructivism/EvG/papers/070.1.pdf

Gorard, S., & Huat See, B. (2009, March 23). The impact of socio-economic status on participation and attainment in science. *Studies in Science Education, 45*(1), 93-129.

Gorard, S., & with Taylor, C. (2004). *Combining methods in educational and social research.* Maidenhead: Open University Press.

Graham, S., Kiuhara, C. A., & MacKay, M. (2020, April). The Effects of Writing on Learning in Science, Social Studies and Mathematics: A Meta-Analysis. *Review of Educational Research, 90*(2), 179-226.

Grek, S. (2009, January 22). Governing by numbers: the PISA 'effect' in Europe. *Journal of Education Policy, 24*(1), 23-37.

Gropen, J., Clark-Chiarelli, N., Hoisington, C., & Ehrlich, S. B. (2011). The Importance of Executive Function in Early Science Education. *CHILD DEVELOPMENT PERSPECTIVES, 5*(4), 298–304.

Halford, G. S., Cowan, N., & Andrews, G. (2007). Separating cognitive capacity from knowledge: a new hypothesis. *TRENDS in Cognitive Sciences, 11*(6), 236-242.

Halford, G. S., Wilson, W. H., & Phillips, S. (1998). Processing capacity defined by relational complexity: Implications for comparative, developmenta and cognitive psychology. *Behavioural and Brain Sciences, 21*, 803-865.

Halfpenny, A. M., & Pettersen, J. (2014). *Introducing Piaget: A guide for practitiioners and students in early years education.* Abingdon: Routeledge. Retrieved January 17, 2017, from http://reader.vlebooks.com/reader/open?accId=10344&cite=1&isbn=9781136280313&maxCopy=17&maxPrint=17&mmLimit=0&notes=1&pageLimit=0&shareLink=%2F%2FWWW.VLEBOOKS.COM%2FVLEWEB%2FPRODUCT%2FINDEX%2F311366&startPage=0&timestamp=2017-01-20T21%3A50%3A26&userId=690

Halpern, D. F. (1998, April). Teaching Critical Thinking for Transfer Across Domains: Depositions, Skills, Structure Training, and Metacognitive Monitoring. *American Psychologist*, 449-456.

Halpern, D. F., Millis, K., Graesser, A. C., Butler, H., Forsyth, C., & Cai, Z. (2012). Operation ARA: A Computerised learning game that teaches critical thinking and scientific reasoning. *Thinking Skills and Creativiity, 7*, 93-100.

Hammersley, M. (2015). Is Social Measurement Possible, and Is It Necessary? . In M. Hammersley, *The Myth of Research-Based Policy & Practice* (pp. 56-71). London: SAGE Publications Ltd.

Hassed, C., & Chambers, R. (2014). *Mindful Learning.* Aukland, New Zealand: Exisle Publising Ply LTD.

Hattie, J. A. (2009). *Visible Learning: A synthesis of over 800 meta-analysis relating to achievement.* Abingdon, Oxon, England: Routledge.

Henry, L. A. (2001). How does the severity of a learning disabilitiy affect working memory performance? In S. E. Gathercole (Ed.), *Short Term and Working Memory* (Vol. 9, pp. 233-247). Hove: Psychology Press.

Himi, S. A., Stadler, M., von Bastian, C. C., Bühner, M., & Hilbert, S. (2022, December). Limits of Near Transfer: Content- and Operation-Specific Effects of Working Memory Training. *Journal of Experimental Psychology: General*, 1-30.

Hollins, A. (2016). ECONOMIC INEQUALITY AND STUDENT ACHIEVEMENT IN READING, MATHEMATICS, AND SCIENCE ACROSS OECD COUNTRIES. *Boston University Thesis Open Access*. Ann Arbor, MI, US: Proquest.

Holman, J., & Yeoman, E. (2018). *Improving Secondary Science.* Retrieved from Education Endowment Foudation: https://educationendowmentfoundation.org.uk/public/files/Support/Publications/Science/EEF_improving_secondary_science.pdf

Holmes, J., & Adams, J. W. (2006). Working Memory and Children's Mathematical Skills: Implications for mathematical development and mathematics curricula. *Educational Psychology, 26*(3), 339-366.

Holmes, J., & Gathercole, S. E. (2014). Taking working memory training from the laboratory into schools. *Educational Psychology, 34*(4), 440-450.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science, 12*(4), F9-F15.

Honrnung, C., Brunner, M., Reuter, R. A., & Martin, R. (2011). Children's Working Memory: Its structure and relationship to fluid intelligence. *Intelligence, 39*, 210-221.

Howard-Jones, P. (2014). *Neuroscience and Education: A Review of Educational Interventions and Approaches Informed by Neuroscience Full Report and Executive Summary.* The University of Bristol on behalf of the Education Endowment Foundation, Graduate School for Education. Millbank: Education Endowment Foundation.

Howe, K. R. (1988). Against the quantitative-qualitative incompatability thesis, or, Dogmas die hard. *Educational Researcher*, 10-16.

Jausovec, N., & Jausovec, K. (2012). Working memory training: Immproving intelligence - Changing brain activity. *Brain and Cognition, 79*, 96-106.

Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the Protective Effects of Mindfulness Training on Working Memory Capacity and Affective Experience. *Emotion, 10*(1), 54-64.

Johann, V. E., & Karbach, J. (2020, July). Effects of game-based and standard executive control training on cognitive and academic abilities in elementary school children. *Developmental Science, 23*(4), 1-18.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher, 33*(7), 14-26.

Jones, J. S., Adlam, A.-L. R., Benattayallah, A., & Milton, F. N. (2022). The neural correlates of working memory training in typically developing children. *Child Development*, 815-830.

Jones, S. E., Fox, C., Gilman, H., James, L., Karic, T., Wright-Bevans, K., & Caines, V. (2013). "I'm being called names and I'm being hit". Challenges of longitudinal research on bullying amongst 11-13 year olds. *Pastoral Care in Education, 31*(4).

Just, M. A., & Carpenter, P. A. (1992). A Capacity Theory of Comprehesion: An individual differences in Working Memory. *Psychological Review, 99*(1), 122-149.

Kandel, E. (2005). Erik Kandel: The Future of Memory (an interview with Erik Kandel). *Molecular Interventions*, 65-68.

Karbach, J., & Verhaegan, P. (2014). Making Working Memory Work: Meta-Analysis of Executive-Control and Working Memory Training in Older Adults. *Psychological Science, 25*(11), 2027-2037.

Karbach, J., Strobach, T., & Schubert, T. (2015). Adaptive working-memory training benefits reading, but not mathematics in middle school. *Child Neuropsychology, 21*(3), 285-301.

Kellogg, R. T. (2001). Competition for working memory among writing processes. *American Journal of Psychology, 114*(2), 175-191.

Kibbe, D. L., Hackett, J., Hurley, M., McFarland, A., Godburn Schubert, K., Schultz, A., & Harris, S. (2011). Ten Years of TAKE 10! :Integrating physical activity with academic concepts in elementary classrooms. *Preventative Medicine*, S43-S50.

Killam, N. (2013, September 24). *Complex Research Terminology Simplified: Paradigms, Ontology, Epistemology and Methodology.* Retrieved September 27, 2017, from YouTube: https://www.youtube.com/watch?v=8xvpxBVCo0c

Killam, N. (2015, September 25). *Ontology, Epistemology, Methodology and Methods in Research Simplified!* Retrieved September 21, 2017, from YouTube: https://www.youtube.com/watch?v=hCOsY5rkRs8

Kim, S. A., & Kasari, C. (2023). Working memory of school-aged children on the autism spectrum: Predictors for longitudinal growth. *Autism*, 1-12.

Kirschner, P. (2017). Stop propagating the learning styles myth. *Computers and Education, 106*, 166-171.

Kirschner, P., & De Bruyckere, P. (2017). The myths of the digital native and the multitasker. *Teaching and Teacher Education, 67*, 135-142.

Kirschner, P., & Karpinski, A. (2010). Facebook and Academic Performance. *Computers in Human Behavior, 26*, 1237-1245.

Kirstein, S., Wersing, H., & Korner, E. (2008). A biologically motivated visual memory architecture for online learning of objects. *Neural Networks, 21*, 65-77.

Klahr, D., & Dunbar, K. (1988). Dual Space Search During Scientific Reasoning. *Cognitive Science, 12*, 1-48.

Klinberg, T. (2010). Training and plasticity of working memory. *Trends in Cognitive Science, 14*, 317-324.

Kornmann, J., Zettler, I., Kammerer, Y., Gerjets, P., & Trautwein, U. (2015). What characterizes children nominated as gifted by teachers? A closer consideration of working memory and intelligence. *High Ability Students, 26*(1), 75-92.

Kounin, J. (1970). *Discipline and Group Management in Classrooms.* New York: Holt, Rinehart and Winston.

Kroczek, B., Ociepka, M., & Chunderski, A. (2016). No Spearman's Law of Diminishing Returns for the working memory and intelligence relationship. *Polish Psychological Bulletin, 47*(1), 73-80.

Kuhn, D., Black, J., Keselman, A., & Kaplan, D. (2000). The Development of Cognitive Skills to Support Inquiry Learning. *Cognition and Instruction, 18*(4), 495-523.

Kuin Lai, M., Wilson, A., McNaughton, S., & Hsiao, S. (2014). Improving Achievement in Secondary Schools: Impact of a Literacy Project on Reading Comprehension and Secondary School Qualifications. *Reading Research Quarterly, 49*(3), 305-334.

Latham, J. (2021, November 21). *Conceptual Framework Fundamentals.* Retrieved from Conceptual Framework Fundamentals: https://i.pinimg.com/originals/ac/8f/27/ac8f27fd9d8241436d85fe7687cb1b3d.png

Le Bigot, N., Passerault, J.-M., & Olive, T. (2012). Visuospatial Processing in Memory for Word Location in Writing. *Experimental Psychology, 59*(3), 138-146.

Lechuga, M. T., Pelegrina, S., Pelaez, J. L., Martin-Puga, M. E., & Justicia, M. J. (2014). Working memory updating as a predictor of Academic Attainment. *Educational Psychology*, 675-690.

Lee, Y.-s., Lu, M.-j., & Ko, H.-p. (2007). Effects of skill training on working memory capacity. *Learning and Instruction, 17*, 336-344.

Leighton, J. P., & Gierl, M. J. (2014). 1-The Learning Science in Educational Assessment: An Introduction. In J. P. Leighton, & M. J. Gierl, *The Learning Science in Educational Assessment: The Role of Cognitive Models* (pp. 1-44). Cambridge: Cambridge University Press.

Leighton, J. P., & Gierl, M. J. (2014). 4-Cognitive Models of Task Performance for Scientific Reasoning and Discovery. In J. P. Leighton, & M. J. Gierl, *The Learning Sciences in Educational Assessment The Role of Cognitive Models* (pp. 115-155). Cambridge: Cambridge University Press.

Leo, E. L., & Galloway, D. (1996). Conceptual links between Cognitive Acceleration through Science Education and Motivational Style: a critique of Adey and Shayer. *International Journal of Science Education, 18*(1), 35-49.

Lessof, C., Ross, A., & Brind-Kantar, R. (2019, June 15). *Multiple disadvantage and KS4 attainment: evidence from LSYPE2 Research report .* Retrieved from Department for Education: https://www.gov.uk/government/publications/multiple-disadvantage-and-ks4-attainment-evidence-from-lsype2

Lewandowsky, S., Oberaurer, K., Yang, L.-X., & Ecker, U. K. (2010). A working memory test battery for MATLAB. *Behavior Research Methods, 42*(2), 571-585.

Lewin, K. (1946). Action Research and Minority Problewms. In K. Lewin, *Resolving Social Conflicts and Field Theory in Social Science* (pp. 143-152). Washington, US: American Psychological Association.

Li, Y., & Bates, T. (2019). You Can’t Change Your Basic Ability, but You Work at Things, and That’s How We Get Hard Things Done: Testing the Role of Growth Mindset on Response to Setbacks, Educational Attainment, and Cognitive Ability. *The Journal of Experimental Psychology: General*, 1640–1655.

Lohaugen, G. C., Antonsen, I., Haberg, A., Gramstad, A., Vik, T., Brubakk, A.-M., & Skranes, J. (2011). Computerized Working Memory Training Improves Function in Adolescents Born at Extremely Low Birth Weight. *The Journal of Pediatrics, 158*(4), 555-561.

Lohman, D. F., & Smith, P. (2014). CAT4 COGNITIVE ABILITIES TEST. *CAT4 COGNITIVE ABILITIES TEST, Fourth Edition*. G L Assessment. Retrieved from http://www.gl-assessment.co.uk/cat4

Lohman, D., & Smith, P. (2014). *G L Assessment*. Retrieved from G L Assessment: http://www.gl-assessment.co.uk/cat4

Loosli, S. V., Buschkuel, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory trainign improves reading processes in typically developing children. *Child Neuropsychology, 18*(1), 62-78.

MacIntyre, A. (1985). *After Virtue: A Study in Moral Theory.* London: Duckworth.

Mackenzie, N., & Knipe, S. (2006). Research Dilemmas: Paradigms, methods and methodology. *Issues in Educational Research, 16*(2), 193-205. Retrieved from http:/www.iier.org.au/iier16/mackenzie.html

Macleod, S., Sharp, C., Danielle, B., Skipp, A., & Higgins, S. (2015). *Supporting the attainment of disadvantaged pupils: articulating success and good practice.* UK Government, Department for Education. London: Department for Education. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/473974/DFE-RR411_Supporting_the_attainment_of_disadvantaged_pupils.pdf

Maehler, C., & Schuchardt, K. (2011). Working Memory In Children with Learning Disabilities: Rethinking the criterion of discrepancy. *International Journal of Disability, Development and Education, 58*(1), 5-17.

Malekpour, M., & Aghababei, S. (2013). The effect of executive functions training on the rate of executive functions and academic performance of students with learning disability. *International Journal of Developmental Disabilities, 59*(3), 145-155.

Martinie, M.-A., Olive, T., & Milland, L. (2010). Cognitive dissonance induced by writing a counterattitudial essay facilitates performance on simple tasks but not on complex tasks that involve working memory. *Journal of Experimental Social Psychology, 46*, 587-594.

Matthews, E., & Adlam, A. (2015, November 21). Working memory, attentional control and mathematics performance in moderate to late preterm children - implications for intervention. *Personal Correspondence to Parent*.

McDonald Connor, C., Kaya, S., Luck, M., Toste, J. R., Canto, A., Rice, D., . . . Underwood, P. S. (2010). Content Area Literacy: Individualizing Student Instruction in Second-Grade Science. *The Reading Teacher, 63*(6), 474-485.

McDonald Connor, C., Morrison, F. J., Fishman, B., Giuliani, S., Luck, M., Underwood, P. S., . . . Schatsneider, C. (2011). Testing the Impact of Child Characteristics x Instruction Interactions on Third Graders' Reading Comprehension by Differentiating Literacy Instruction. *Reading Research Quarterly, 46*(3), 189-221.

McDonald, C. C., Kaya, S., Luck, M., Toste, J. R., Canto, A., Rice, D., . . . Underwood, P. S. (2010). Content Area Literacy: Individualizing Student Instruction in Second-Grade Science. *The Reading Teacher, 63*(6), 474-485.

McDonald, C. C., Morrison, F. J., Fishman, B., Giuliani, S., Luck, M., Underwood, P. S., . . . Schatsneider, C. (2011). Testing the Impact of Child Characteristics x Instruction Interactions on Third Graders' Reading Comprehension by Differentiating Literacy Instruction. *Reading Research Quarterly, 46*(3), 189-221.

McGowan, M. R., Holtzman, D. R., Coyne, T. B., & Miles, K. L. (2016). Predictive Ability of the SB5 Gifted Composite Versus the Full-Scale IQ Among Children Referred for Gifted Evaluation. *Roeper Review, 38*, 40-49.

McLellan, R. (2006, June 1). The impact of motivation "World-view" on engagement with a cognitive accelleration program. *International Journal of Science Education, 28*(7), 781-819.

McLeod, S. (2007 updated 2014). *Lev Vygotsky*. Retrieved January 23, 2017, from Simply Psychology: http://www.simplypsychology.org/vygotsky.html

McLeod, S. (2009 Updated 2015). *Piaget*. Retrieved January 21, 2017, from Simply Psychology: http://www.simplypsychology.org/piaget.html

McLeod, S. (2014). *Lev Vygotsky*. Retrieved January 23, 2017, from Simply Psychology: http://www.simplypsychology.org/vygotsky.html

McLeod, S. (2015). *Piaget*. Retrieved January 21, 2017, from Simply Psychology: http://www.simplypsychology.org/piaget.html

McNeil, F. (2009). *Learning with the Brain in Mind.* London: SAGE Publications LTD.

Melby-Lervag, M., & Hulme, C. (2016). There is no convincing evidence that working memory is effective: A reply to Au et al. (2014) and Karbach and Verhaegen (2014). *Psychonomic Bulletin Review, 23*, 324-330.

Mertens, D. M. (2010). Philosophy in mixed methods teaching: The transformative paradigm as illustration. *International Journal of Mulitple Research Approaches, 4*, 9-18.

Miller, G. A. (1994 (1956)). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review, 101 (63)*(2), 343-352 (81-97).

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variables Analysis. *Cognitive Psychology, 41*, 49-100.

Mokhemar, M. A. (1999). *The Central Auditory Processing Kit: Book 1* (Vol. 1). East Moline, Illinois, USA: LinguiSystems Incorporated.

Moore, A., Fairhurst, P., Correia, C., Harrison, C., & Bennett, J. (2020). Science practical work in a COVID-19 world: are teacher demonstrations, videos and textbooks effective replacements for hands-on practical activities? *School Science Review*, 7-12.

Morey, R. D., & Morey, C. C. (2011). WOMMBAT: A user interface for hierachical Bayesian estimation of working memory capacity. *Behavioural Research, 43*, 1044-1065. doi:10.3758/s13428-011-0114-8

Morgan, D. L. (2007, January). Paradigms Lost and Pragmatism Gained Methodological Methods of Combining Qualitative and Quantitative Methods. *Journal of Mixed Methods Research, 1*(1), 48-76.

Mueller, S. T., & Piper, B. J. (2014). The Psychology Experiment Builder Language (PEBL) and PEBL Test Battery. *Journal of Neuroscience Methods, 222*, 250-259.

Muñez, D., Lee, K., Bull, R., Khng, K. H., Cheam, F., & Rahim, R. A. (2023). Working memory and numeracy training for children with math learning difficulties: Evidence from a large-scale implementation in the classroom. *Journal of Educational Psychology, 114*(8), 1866–1880.

Murdock, B. B., & Walker, K. D. (1969, October 1). Modality Effects in Recall. *Journall of Learning and Verbal Behavior, 8*(5), 665-676.

NEU. (2019, March 25). *School Funding: new analysis shows £5.4bn cut from school budgets in England since 2015*. Retrieved December 29, 2019, from NEU: https://neu.org.uk/funding/school-funding-new-analysis-shows-cut-from-school-budgets

Novak, J. D. (1977). *A Theory of Education.* London: Cornwell Universtiy Press.

Nyroos, M., & Wiklund-Horngvist, C. (2011). The association between working memory and educational attainment as measured in different mathematical subtopics in the Swedish national assessment: primary education. *Educational Psychology, 32*(2), 239-256.

Oberauer, K., Suss, H. ..-M., Wilhelm, O., & Wittmann, W. (2000). Working memory capacity - facets of a cognitive ability construct. *Personality and Individual Differences, 29*, 1017-1045.

Ofsted. (2019, November 15). *School Inspection Handbook.* Retrieved from Department for Education: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/843108/School_inspection_handbook_-_section_5.pdf

Ofsted. (2019, January 16). *The Education Inspection Framework.* Retrieved from Gov.Uk: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770924/Proposed_education_inspection_framework_draft_for_consultation_140119.pdf.pdf

O'Hare, L., Stark, P., McGuiness, C., Biggart, A., & Thurston, A. (2017). *Education Endowment Foundation.* Retrieved from Spaced learning: SMART spaces evaluation', Education Endowment Foundation: https://educationendowmentfoundation.org.uk/projects-andevaluation/projects/spaced-learning/

Olinghouse, N. G. (2008). Student- and instruction-level predictors of narrative writing in third grade students. *Reading and Writing, 21*, 3-26.

Olive, T. (2004). Working Memory in Writing: Empirical Evidence From the Dual-Task Technique. *European Psychologist, 9*(1), 32-42.

Olive, T., Kellogg, R. T., & Piolat, A. (2008). Verbal, visual, and spatial working memory demands during text composition. *Applied Psycholinguistics, 29*, 669-687.

Oliver, M. (2016, December 7). Lecture at Exeter University on Neuropsychology in Education including CASE.

Paas, F., & Ayres, P. (2014). Cognitive Load Theory: A Broader View on the Role of Working Memory in Learning and Education. *Education Psychology Review, 26*, 191-195.

Packiam Alloway, T. (2007). *Automated Working Memory Assessment Manual.* London, United Kingdom: Pearson Assessment.

Packiam Alloway, T. (2009). Working Memory, but Not IQ Predicts Subsequent Learning in Children with Learning Difficulties. *European Journal of Psychological Assessment, 25*(2), 92-98.

Packiam Alloway, T., & Alloway, R. (2015). *Understanding Working Memory.* London: SAGE Publications Ltd.

Packiam Alloway, T., Banner, G. E., & Smith, P. (2010). Working Memory and Cognitive Styles in adolescents' attainment. *British Journal of Educational Psychology, 80*, 567-581.

Panadero, E. (2017, April 28). A Review of Self-regulated Learning: Six Models and Four Directions for Research. *Frontiers in Psychology*, 1-28.

Pascoe, L., Roberts, G., Doyle, L. W., Lee, K. J., Thompson, D. K., Seal, M. L., . . . Anderson, P. J. (2013). Preventing academic difficulties in preterm children: a randomised controlled trial of an adaptive working memory training intervention- IMPRINT study. *BMC Pediatrics, 13*(144), 1-12.

Peng, P., & Fuchs, D. (2016). A Meta-Analysis of Working Memory Deficits with Children with Learning Difficulties:Is there a difference between verbal domain and numerical domain? *Journal of Learning Disabilities, 49*(1), 3-20.

Peng, P., & Swanson, H. L. (2022). The domain-specific approach of working memory training. *Developmental Review, 65*, 1-19.

Peng, P., Namkung, J., Barnes, M., & Sun, C. (2015, September 7). A Meta-Analysis of Mathematics and Working Memory: Moderating Effects of Working Memory Domain, Type of Mathematics Skill, and Sample Characteristics. *Journal of Educational Psychology*, 1-19.

Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD.

Phillips, P. (2006). Comparative Education: method. *Research in Comparative and International Education, 1*(4), 304-319.

Piaget, J., & Inhelder, B. (2015 (first published 1973 in English)). *Memory and Intelligence.* Hove: Psychology Press Hove. Retrieved January 25, 2017, from http://lib.myilibrary.com/Open.aspx?id=768137

Pilegard, C., & Fiorella, L. (2016, December). Helping students help themselves: Generative learning strategies improve middle school students' self-regulation in a cognitive tutor. *Computers in Human Behavior, 65*, 121-126.

Pimperton, H., & Nation, K. (2014). Poor Comprehenders in the Classroom: Teacher Ratings of Behaviour in Children With Poor Reading Comprehension and Its relationship with Individual Differences in Working Memory. *Journal of Learning Disabilities, 47*(3), 199-207.

Posner, M. I., & Rothbart, M. K. (2005, March). Influencing brain networks: implications for education. *TRENDS in Cognitive Sciences, 9*(3), 99-103.

Prain, V., Waldrip, B., Sbaglia, R., & Lovejoy, V. (2017, March). Towards personalising learning in school science: Making this learning more relevant. *Teaching Science, 63*(1), 27-33.

Quartaroli, M. T. (2012). Program Evaluation. In S. D. Lapan, M. T. Quartaroli, & F. J. Riemer, *Qualatitive Research: An introduction to methods and designs* (pp. 321-344). Hoboken, New Jersey, US: Jossey-Bass.

Ramani, G. B., Daubert, E. N., Lin, G. C., Kamarsu, S., Wodzinski, A., & Jaeggi, S. M. (2020, July). Racing dragons and remembering aliens: Benefits of playing number and working memory games on kindergartners' numerical knowledge. *Developmental Science, 23*(4), 1-17.

Randall, L., & Tyldesley, K. (2016). Evaluating the impact of working memory. *Educational & Child Psychology, 33*(1), 34-50.

Raver, C., Jones, S., Li-Grining, C., Zhai, F., Bub, K., & Pressler, E. (2011, January/February). CSRP's Impact on Low-Income Preschooler's Preacademic Skills: Self-Regulation as a Mediating Mechanism. *Child Development, 82*(1), 362-378.

Rawlings, N. (2015, February). Exercise and the brain. *Biological Sciences Review, 27*(3), pp. 34-37.

Redick, T., Shipstead, Z., Wiemers, E., Melby-Lervag, M., & Hulme, C. (2015). What's Working in Working Memory Training? An Education Perspective. *Education Psychology Review*, 617-633.

Renshaw, I., Davids, K., Araujo, D., Lucas, A., Roberts, W. M., Newcombe, D. J., & Franks, B. (2019, January). Evaluating Weaknesses of "Perceptual-cognitive Training" and "Brain Training" Methods in Sport: An Ecological Dynamics Critique. *Frontiers in Psychology, 9*, 1-12.

Reynolds, C. R., & Voress, J. K. (2007). *TOMAL 2 Test of Memory and Learning : Examiner's Manuel* (2nd ed.). Austin, Texas, USA: PRO-ED Inc.

Ricard, M. (2007). *Happiness: A guide to developing life's most important skill.* London, UK: Atlantic Books: An Imprint of Atlantic Grove LTD.

Riding, R. J., Grimley, M., Dahraei, H., & Banner, G. (2003). Cognitive style, working memory and learning behaviour and attainment in school subjects. *British Journal of Educational Psychology, 73*, 149-169.

Riggs, N., Greenberg, M., Kusche, C., & Pentz, M. A. (2006, March). The Mediational Role of Neurocognition in the Behavioral Outcomes of a Social-Emothional Prevention Program in Elementary School Students: Effects of the PATHS Curriculum. *Prevention Science, 7*(1), 91-102.

Rode, C., Robson, R., Andy, P., Geary, D. C., & Mayr, U. (2014, August). Is Working Memory Training Effective? A Study in a School Setting. *PLOS ONE, 9*(8), 1-8.

Rode, C., Robson, R., Purviance, A., Geary, D. C., & Mayr, U. (2014, August). Is Working Memory Training Effective? A Study in a School Setting. *PLOS ONE, 9*(8), 1-8.

Roediger, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: taking memory tests improves long-term retention. *Psychological Science, 17*(3), 249-255.

Roth, W.-M. (1999). Authentic School Science: Intellectual Traditions. In R. McCormick, P. Carrie, R. McCormick, & P. Carrie (Eds.), *Learning and Knowledge* (pp. 6-20). London: The Open University (Paul Chapman Publishing LTD).

Rueda, M. R., Checa, P., & Combita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience, 2S*, S192-S204.

Salehi, K., & Golafshani, N. (2010). Using Mixed Methods in Reseach Studies: An Opportunity with its Challenges. *International Journal of Multiple Research Approaches, 4*, 186-191.

Sardar, Z. (2000). *Thomas Kuhn and the Science Wars.* Duxford: Icon Books LTD.

Scriven, M. (2008). A summative evaluation of RCT methodology and an alternative approach to causal research. *Journal of Multidisciplinary Evaluation, 5*(9), 11-24.

Service, E., & Turpeinen, R. (2001). Working memory in spelling: Evidence from backward typing. In S. E. Gathercole (Ed.), *Short-term and Working Memory* (Vol. 9, pp. 395-421). Hove: Psychology Press.

Shana, Z., & Abulibdeh, E. S. (2020). SCIENCE PRACTICAL WORK AND ITS IMPACT ON STUDENTS'. *Journal of Technology and Science Education*, 199-215.

Shaywitz, S. E., Shaywitz, B. A., Fulbright, R. K., Skudlarski, P., Einar, M. W., Constable, T., . . . Gore, J. C. (2003). Neural Systems for Compensation and Persistance: Young Adult Outcome of Childhood Reading Disability. *Biologial Psychiatry, 54*, 25-33.

Sheehan, M., & Johnson, R. B. (2012). Philosophical and methodological beliefs of instructional design faculty and professionals. *Education Technology Research Development, 60*, 131-153.

Shipstead, Z., Redick, T. S., & Engle, R. W. (2012). Is Working Memory Training Effective? *Psychologial Bulletin, 138*(4), 628-654.

Smicker, M., Schwefel, M., Vellage, A.-K., & Muller, N. G. (2016). Training of Attentional Filtering, but Not of Memory Storage, Enhances Working Memory Efficiency by Strengthening the Neuronal Gatekeeper Network. *Journal of Cognitive Neuroscience*, 636-642.

Smith, Jonides, & Koeppe, R. A. (1996). Working Memory in Humans Neuropsychological Evidence. In M. (. Gazzaniga, *The New Cognitive Neurosciences* (pp. 1009-1011). Cambridge: MA:MIT Press.

Spencer-Smith, M., Quach, J., Mensah, F., Roberts, G., Gathercole, S., Wake, M., & Anderson, P. J. (2020, December). The Effectiveness of Working Memory Training for Children With Low Working Memory. *Pediatrics, 146*(6), 1-9.

St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children’s working memory and classroom performance. *Educational Psychology, 30*(2), 203–219.

St. Clair-Thompson, H. (2015, February). Lucid Recall. *Lucid Recall*. G L Assessment. Retrieved from https://www.gl-assessment.co.uk/products/lucid-recall/

Stake, R. E. (1995). *An Intensive Study of Case Study Research Methods.* Thousand Oaks, CA, US: SAGE.

Stanovich, K. E., West, R. F., & Toplak, M. E. (2013). Myside Bias, Rational Thinking, and Intelligence. *Current Directions in Psychological Science, 22*(4), 259-264.

Stone, J. (2015). *Cognitive Research Tools*. Retrieved May 21, 2017, from Cognitive Research Tools: http://www.cognitivetools.uk/cognition/

Stone, J., & Towse, J. (2015). A Working Memory Test Battery: Java-Based Collection of Seven Working Memory Tasks. Journal of Open Research Software. *Journal of Open Research Software, 3*(1), p.e5. doi:http://doi.org/10.5334/jors.br

Strand, S. (2014). School effects and ethnic, gender and socioeconomic. *Oxford Review of Education, 40*(2), 223-245.

Studer-Luethi, B., Toermaenen, M., Margelisch, K., Hogrefe, A. B., & Perrig, W. J. (2022). Effects of Working Memory Training on Children’s Memory and Academic Performance: the Role of

Training Task Features and Trainee's Characteristics. *Journal of Cognitive Enhancement*, 340–357.

Sumeraki, M., Nebel, C., Kuepper-Tetzel, C., & Need Kaminski, A. (2021, September 3). *Downloadable Materials*. Retrieved from The Learning Scientists: https://www.learningscientists.org/downloadable-materials

Sumeraki, M., Nebel, C., Kuepper-Tetzel, C., & Need Kaminski, A. (2021, September 3). *Podcast on Elaborative Interrogation*. Retrieved from Learning Scientists: https://www.learningscientists.org/learning-scientists-podcast/2017/11/1/episode-6-elaborative-interrogation

Swanson, H. L., & Berninger, V. W. (1996). Individual Differences in Children's Working Memory and Writing Skill. *Journal of Experimental Child Psychology, 63*, 358-385.

Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working Memory, Short- Term Memory, and Reading Disabilities: A Selective Meta-Analysis of the Literature. *Journal of Learning Disabilities, 42*(3), 260-287.

Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science, 12*, 257-285.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research.* Thousand Oaks, California: SAGE.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: integrating quantitative and qualitative approaches in social and behavioral sciences.* Thousand Oaks California: Sage.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: integrating quantitative and qualitative approaches in social and behavioral sciences.* Thousand Oaks California: Sage.

Tehan, G., Hendry, L., & Kocinski, D. (2001). Word length and phonological similarity effects in simple, complex, and delayed serial recall tasks: Implications for working memory. In S. E. Gathercole (Ed.), *Short-term and Working Memory* (pp. 333-348). Hove: Psychology Press.

Teng, F. (., & Huang, J. (2019). Predictive Effects of Writing Strategies for Self-Regulated Learning on Secondary School Learners' EFL Writing Proficiency. *Tesol Quarterly*, 232-247.

Terezinha, N., Bryant, P., Strand, S., Hillier, J., Barros, R., & Miller-Friedman, J. (2017, September 2017). *Science Review of SES and Science Learning in Formal Educational Settings.* Retrieved from Education Endowment Foundation: https://educationendowmentfoundation.org.uk/evidence-summaries/evidence-reviews/science/

Thomas, G. (2017). *How To Do Your Research Project.* London: Sage Publications Ltd.

Thomas, G. (2017). *How To Do Your Research Project: A Guide for Students* (3rd ed.). London: Sage Publications LTD.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training. *Psychological Research, 78*, 852-868.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training. *Psychological Research, 78*, 852-868.

Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. *Psychological Research, 78*, 852-868.

Torgerson, C. J., & Torgerson, D. J. (2008). *Designing randomised trials in health, education and the social sciences: an introduction.* New York: Palgrave Macmillan.

Unknown. (2011, July 1). *Gov.uk.* Retrieved October 17, 2017, from https://www.gov.uk/government/publications/teachers-standards: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283566/Teachers_standard_information.pdf

Unknown. (2012, August 30). *Intoduction to Epistemology by The Academy Ideas*. Retrieved September 20, 2017, from YouTube: https://www.youtube.com/watch?v=X3IcbRNQR4c

Unknown. (2012, August 30). *Introduction to Epistemology by The Academy Ideas*. Retrieved September 20, 2017, from YouTube: https://www.youtube.com/watch?v=X3IcbRNQR4c

Unknown. (2012, 10 5). *Why Design Needs A Critical Reality Check*. Retrieved 6 22, 2017, from I Think I Design: https://ithinkidesign.wordpress.com/2012/10/

Unknown. (2018, April 23). *Do Brain Training Apps Really Work?* Retrieved from FYK Technology: https://fykmobile.com/articles/brain-tranning.html

Unknown. (2019, January 16). *Gov.uk.* Retrieved from Education inspection framework Overview of research: https://www.gov.uk/government/publications/education-inspection-framework-overview-of-research

Unknown. (2023, February 2). *Finding the optimum: the science subject report.* Retrieved from Ofsted: https://www.gov.uk/government/publications/subject-report-series-science/finding-the-optimum-the-science-subject-report--2#:~:text=The%20report%20evaluates%20the%20common,2021%20Ofsted%20science%20research%20review.

Unknown. (n.d.). *NEPSY - Second Edition (NEPSY-II)*. Retrieved May 17, 2017, from Pearson Clinical: http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildGeneralAbilities/NEPSY-SecondEdition(NEPSY-II)/NEPSY-SecondEdition(NEPSY-II).aspx

Unknown. (n.d.). *Ontology*. Retrieved June 20, 2017, from Philosophy Terms: http://philosophyterms.com/ontology/

Unknown. (n.d.). *Test of Memory and Learning - Second Edition (TOMAL-2)*. Retrieved 6 18, 2017, from Pearson Clinical : http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildMemory/tomal-2/test-of-memory-and-learning-second-edition.aspx

Unknown. (n.d.). *Wechsler Intelligence Scale for Children ® - Fifth UK Edition (WISC-V UK)*. Retrieved May 5, 2017, from Pearson Clinical: http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildGeneralAbilities/wisc-v/wechsler-intelligence-scale-for-children-fifth-uk-edtion-wisc-v-uk.aspx

Unknown. (n.d.). *Working Memory Rating Scale (WMRS)*. Retrieved May 4, 2017, from Pearson Clininal: http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildMemory/WorkingMemoryRatingScale(WMRS)/WorkingMemoryRatingScale(WMRS).aspx

Unknown. (n.d.). *Working Memory Test Battery for Children (WMTB-C)*. Retrieved May 4, 2017, from Pearson Clinical: http://www.pearsonclinical.co.uk/Psychology/ChildCognitionNeuropsychologyandLanguage/ChildMemory/WorkingMemoryTestBatteryforChildren(WMTB-C)/WorkingMemoryTestBatteryforChildren(WMTB-C).aspx

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005, August). An automated version of the operation span task. *Behavior Research Methods, 37*(3), 498-505.

Van de Sande, E., Segers, E., & Verhoeven, L. (2016). Supporting executive functions during children's prelitereacy learning with computer. *Journal of Computere Assisted Learning, 32*, 468-480.

Van der Molen, M. J., Van Luit, J. E., Van der Molen, M. W., Klugkist, I., & Jongmans, M. (2010). Effectiveness of a computerised working memory in adolescents with mild to borderline intellectual disabilities. *Journal of Intellectual Disability Research, 54*(5), 433-447.

Vanderberg, R., & Swanson, H. L. (2007). Which Components of working memory are important in the writing process? *Read Writ, 20*, 721-752.

Venville, G., & Oliver, M. (2015). The Impact of a cognitive acceleration programme in science on students in an academically selective high school. *Thinking Skills & Creativity, 15*, 48-60.

Venville, G., Oliver, M., & Adey, P. (2012). Effects of a Cognitive Accleration Programme in a Low Socioeconic High School in Regional Australia. *International Journal of Science Education, 34*(9), 1393-1410.

Vernucci, S., Canet-Juric, Lorena, & Richards, M. M. (2023). Effects of working memory training on cognitive and academic abilities in typically developing school-age children. *Psychological Research* , 308–326.

Wang, C.-L., & Liou, P.-Y. (2017). Students' motivational beliefs in science learning, school motivational contexts and science achievement in Taiwan. *International Journal of Science Education, 39*(7), 898-917.

Wang, T., Ren, X., Altmeyer, M., & Schweizer, k. (2013). An account of the relationship between fluid intelligence and complex learning in considering storage capacity and executive attention. *Intelligence, 41*, 537-545.

Wass, S. V. (2015). Applying cognitive training to target executive functions during early development. *Child Neuropsychology, 21*(2), 150-166.

Wass, S., Parayska-Pomsta, K., & Johnson, M. H. (2011, September 27). Training Attentional Control in Infancy. *Current Biology, 21*, 1543-1547.

Weare, K. (2012, April). *Evidence for the Impact of Mindfulness on Young People and Children*. Retrieved February 1, 2018, from Mindfulness In Schools Project: https://mindfulnessinschools.org/wp-content/uploads/2013/02/MiSP-Research-Summary-2012.pdf

Weaver, K. (2018). Pragmatic Paradigm. In K. Weaver, *The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation* (pp. 1287-1288). Online: SAGE Publishing.

West, M., Anscow, M., Wigelsworth, M., & Troncoso, P. (2017, July 1). *Challenge the gap Evaulation report and Executive Summary.* Retrieved from Education Endowment Foundation: https://educationendowmentfoundation.org.uk/projects-and-evaluation/projects/challenge-the-gap/

Westerburg, H., & Klinberg, T. (2007). Changes in cortical activity after training of working memory - a single-subject analysis. *Physiology and Behavior, 92*, 186-192.

White, C., Gibb, J., Lea, J., & Street, C. (2017, August). *Developing Character Skills In Schools.* Retrieved February 2018, 2018, from Department of Education: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/634712/Developing_Character_skills-Case_study_report.pdf

Wiest, D. J., Wong, E. H., Bacon, J. M., Rosales, K. P., & Wiest, G. M. (2020, March/April). The effectiveness of computerized cognitive training on working memory in a school setting. *Applied Cognitive Psychology, 34*(2), 465-471.

Willingham, D. T. (2012, Fall). Measured Approach or Mythical Elixir: How to tell good science from bad. *American Educator*, 4-10, 38-40.

Willingham, D. T. (2018). Unlocking The Science of How Kids Think: A New Proposal for Reforming Teacher Education. *Education Next*, 42-49.

Wonguparraj, P., Kumari, V., & Morris, R. G. (2015). The relation between a multicomponent working memory and intelligence: The roles of central executive and short-term storage functions. *Intelligence, 53*, 166-180.

Yeniad, N., Malda, M., Mesman, J., van Ijzendoorn, M. H., & Pieper, S. (2013). Shifting ability predicts math and reading performance in chlidren: A meta-analytical study. *Learning and Individual Differences, 23*, 1-9.

Yong Tan, C. (2019, June). Involvement Practices, Socioeconomic Status, and Student Science Achievement: Insights From a Typology of Home and School Involvement Patterns. *American Educational Research Journal, 56*(3), 899–924 .

Zeidan, F., Johnson, S. K., Diamond, B. J., David, Z., & Goolkasian, P. (2010). Mindfulness meditation improves cognition: Evidence of brief mental training. *Consciousness and Cognition, 19*, 597-605.

Appendices

Appendix A: Literature Review: The Tables to show for each section of the literature review the literature chosen, the source of the literature and justification

Introduction Appendix A

Appendix A has Tables 29-37. Each table contains information on the literature chosen for each section of the literature review (Chapter 2), the source of the literature (whether it came from a search or was sourced via a scattergun approach due to the lack of literature in this area) and a justification of why the literature was chosen for that specific section of the literature review.

Table 29 The literature included in Section 2.4 of the literature review, the source of the literature and justification for using the literature

Studies Included in Section 2.4 of the Literature Review	Source of Literature	Summary of how this study was useful for Section 2.4 of the Literature Review
Halpern, D. F., Millis, K., Graesser, A. C., Butler, H., Forsyth, C., & Cai, Z. (2012). Operation ARA: A Computerised learning game that teaches critical thinking and scientific reasoning. *Thinking Skills and Creativiity, 7*, 93-100.	Scattergun	A computerised training study, with uni aged students linked to improving critical thinking and scientific reasoning skills using a computer program
Holmes, J., & Gathercole, S. E. (2014). Taking working memory training from the laboratory into schools. *Educational Psychology, 34*(4), 440-450.	Search	WM training study conducted in schools looking at improving attainment
Rode, C., Robson, R., Purviance, A., Geary, D. C., & Mayr, U. (2014, August). Is Working	Search	WM training study in a school looking at improving attainment

Memory Training Effective? A Study in a School Setting. *PLOS ONE, 9*(8), 1-8.		
Cunningham, J., & Sood, K. (2016). How effective are working memory training interventions at improving maths in schools: a study into the efficacy of working memory training in children aged 9 and 10 in a junior school? *Education 3-13*, 1-14.	Searc h	WM training in schools in Mathematics looking at improving learning skills and attainment
Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Education Psychology Review, 26*, 197-223.	Scatt ergu n	WM and its' importance for learning
Dehn, M. J. (2008). *Working Memory and Academic Learning: Assessment and Intervention.* New Jersey: John Wiley & Sons Inc.	Scatt ergu n	WM and its' importance for learning
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal	Scatt ergu n	WM is important for learning

Lobe" Tasks: A Latent Variables Analysis. *Cognitive Psychology, 41*, 49-100.		
Hassed, C., & Chambers, R. (2014). *Mindful Learning.* Aukland, New Zealand: Exisle Publising Ply LTD.	Scattergun	WM is important for learning
Petty, G. (2009). *Evidence Based Teaching* (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD.	Scattergun	Student WM can be overloaded in classroom settings, this prevents effective learning taking place
Willingham, D. T. (2018). Unlocking The Science of How Kids Think: A New Proposal for Reforming Teacher Education. *Education Next*, 42-49	Scattergun	ITE training doesn't focus explicitly on WM in ITE students so could be unaware of its importance in students learning in their classrooms.
Unknown. (2011, July 1). *Gov.uk.* Retrieved October 17, 2017, from https://www.gov.uk/government/publications/teachers-standards: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283566/Teachers_standard_information.pdf	Retrieved purposely for referencing	To demonstrate that an awareness of WM is not an explicit requirement of the teachers' standards

Table 30 The literature included in Section 2.3 of the literature review, the source of the literature and justification for using the literature

Studies Included in Section 2.3 of the Literature Review	Source of Literature	Summary of how this study was useful for Section 2.3 of the Literature Review
Dehn, M. J. (2008). *Working Memory and Academic Learning: Assessment and Intervention.* New Jersey: John Wiley & Sons Inc.	Scattergun	Gives context to the different WM models
Kandel, E. (2005). Erik Kandel: The Future of Memory (an interview with Erik Kandel). *Molecular Interventions*, 65-68	Scattergun	Demonstrates how the WM physically interacts with the LTM – and the limitations of our current understanding of this
Alloway, T. P., & Gathercole, S. E. (2009). *Working Memory and Learning: A Practical Guide for Teachers.* London: SAGE Publications.	Search	Use the Baddeley and Hitch model of WM as a framework for their research with school aged students
Holmes, J., & Gathercole, S. E. (2014). Taking working memory training from the laboratory	Search	Use the Baddeley and Hitch model of WM as a framework

into schools. *Educational Psychology, 34*(4), 440-450		for their research with school aged students
Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualsing Working Memory in Educational Research. *Education Psychology Review, 27*, 333-351	Search	Using the Baddeley and Hitch model of WM as a framework for their research with school aged students. Justifying this model as measurable and linking to learning. How other models are linked to EF and attention focus but are difficult to measure and more challenging to link to learning in a quantitative way.
Smith, Jonides, & Koeppe, R. A. (1996). Working Memory in Humans Neuropsychological Evidence. In M. (. Gazzaniga, *The New Cognitive Neurosciences* (pp. 1009-1011). Cambridge: MA:MIT Press.	Scattergun	Demonstrating that some of the different WM models are related to EF (how much EF is related to CE WM function)
Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working Memory, Short-Term Memory, and	Scattergun	Demonstrating that some of the different WM models are related to EF (how much EF is related to CE WM function) &

General Fluid Intelligence: A Latent-Variable Approach. *Journal of Experimental Psychology: General, 128*(3), 309-331.		attention focus. Furthermore, how WM may be related to Gf. Supports the EF CE aspect of the Baddeley & Hitch model of WM
Baddeley, A. D. (2001, November). Is Working Memory Still Working? *American Psychologist*, 851-864.	Search	Demonstrating that some of the different WM models are related to EF (how much EF is related to CE WM function)
Anderson, J. R. (1990). *Cognitive Psychology and its' Implications.* New York: W H Freeman and Company.	Scattergun	Demonstrating how some of the models of WM concentrate on the need for attention focus for LTM learning to take place
Oberauer, K., Suss, H. ..-M., Wilhelm, O., & Wittmann, W. (2000). Working memory capacity - facets of a cognitive ability construct. *Personality and Individual Differences, 29*, 1017-1045.	Scattergun	Demonstrating how some of the models of WM concentrate on the need for attention focus for LTM learning to take place

Tehan, G., Hendry, L., & Kocinski, D. (2001). Word length and phonological similarity effects in simple, complex, and delayed serial recall tasks: Implications for working memory. In S. E. Gathercole (Ed.), *Short-term and Working Memory* (pp. 333-348). Hove: Psychology Press	Scattergun	Demonstrating how some of the models of WM concentrate on the need for attention focus for LTM learning to take place
Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Education Psychology Review, 26*, 197-223.	Scattergun	WM and its' importance for learning
Ericsson, K. A., & Kinsch, W. (1995). Long-Term Working Memory. *Psychological Review, 102*(2), 211-245.	Scattergun	Supporting the model that WM is a subset of LTM. Making the impact of improving WM on LTM very difficult to measure Supports the EF CE aspect of the Baddeley & Hitch model of WM

Cowan, N. (1988). Evolving Conceptions of Memory Storage, Selective Attention, and Their Mutual Constraints Within the Human Information-Processing System. *Psychological Bulletin, 104*(2), 163-191.	Scattergun	Supporting the model that WM is a subset of LTM & requires attention focus to activate LTM. Making the impact of improving WM on LTM very difficult to measure
Baddeley, A. D., & Hitch, G. (1974). In G. H. Bower, & G. H. Bower (Ed.). London: Academic Press.	Search	Shows the original tripartite model of WM
Baddeley, A. (2014). *Essentials Of Human Memory* (Classic ed.). Hove, East Sussex, England: Psychology Press.	Scattergun	Demonstrates the most recent model of WM, a model that is effective to use in educational research
Cowan, N., Elliott, E. M., Saults, S. J., Morey, C. C., Mattox, S., Hismjatullina, A., & Conway, A. R. (2005). On the capcity of attention: Its estimation and its role in working memory and	Scattergun	Provides supporting evidence for the function of the Baddeley and Hitch WM model

cognitive aptitudes. *Cognitive Psychology, 51*, 42-100.		
Miller, G. A. (1994 (1956)). The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Review, 101 (63)*(2), 343-352 (81-97).	Scattergun	Gives context to the development of WM models
Baddeley, A. D. (2001, November). Is Working Memory Still Working? *American Psychologist*, 851-864.	Search	Demonstrates the most recent model of WM, a model that is effective to use in educational research
Demetriou, A., Spanoudis, G., Shayer, M., van der Van, S., Brydges, C. R., Kroesbergen, E., . . . Swanson, H. L. (2014). Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modelling of 14 studies. *Intelligence, 46*, 107-121.	Search	Supports the theory that EF part of WM is linked to Gf and could possibly be developed.

Table 31 The literature included in Section 2.5 of the literature review, the source of the literature and justification for using the literature

Studies Included in Section 5 of the Literature Review	Source of Literature	Summary of how this study was useful for Section 5 of the Literature Review
Adey, P., & Shayer, M. (1993). An Exploration of Long-Term Far-Transfer Effects Following An Extended Intervention Program in the High School Curriculum. *Cognition and Instruction, 11*(1), 1-29.	Scattergun	To demonstrate CASE is an effective science learning strategy
Benjamin, A., & Tullis, J. (2010, November). What makes distributed practice effective? *Cognitive Psychology, 61*(3), 228-247.	Scattergun	To evidence distributed practice as an effective learning strategy
Black, P., & Wiliam, D. (1998). *Inside The Black Box: Raising Standards Through Classroom Assessment.* Cambridge: King's College London, School of Education. nferNelson.	Already knew	To evidence students improving their work promptly after marking as an effective strategy for learning

Demetriou, A., Spanoudis, G., Shayer, M., van der Van, S., Brydges, C. R., Kroesbergen, E., . . . Swanson, H. L. (2014). Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modelling of 14 studies. *Intelligence, 46*, 107-121.	Search	To evidence that WM changes during cognitive development of the child
Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. *Metacognition Learning*, 231-264.	Search	To evidence of self-regulated learning as an effective strategy for learning
Howard-Jones, P. (2014). *Neuroscience and Education: A Review of Educational Interventions and Approaches Informed by Neuroscience Full Report and Executive Summary.* The University of Bristol on behalf of the Education Endowment Foundation, Graduate School for Education. Millbank: Education Endowment Foundation.	Search	To evidence spaced learning and retrieval practice as an effective strategy for learning
Kirschner, P., & De Bruyckere, P. (2017). The myths of the digital native and the multitasker. *Teaching and Teacher Education, 67*, 135-142.	Scattergun	To evidence considering student as digital natives or multitaskers is a

		not effective strategy for learning
Kirschner, P., & Karpinski, A. (2010). Facebook and Academic Performance. *Computers in Human Behavior, 26*, 1237-1245.	Scattergun	To evidence use of social media is not an effective strategy for learning and is linked to task switching which has a detrimental effect on learning
Klahr, D., & Dunbar, K. (1988). Dual Space Search During Scientific Reasoning. *Cognitive Science, 12*, 1-48.	Search	To evidence dual spaced search as an effective strategy for learning science
Kuin Lai, M., Wilson, A., McNaughton, S., & Hsiao, S. (2014). Improving Achievement in Secondary Schools: Impact of a Literacy Project on Reading Comprehension and Secondary School Qualifications. *Reading Research Quarterly, 49*(3), 305-334.	Search	To evidence reading comprehension activities as an effective strategy for learning
Leo, E. L., & Galloway, D. (1996). Conceptual links between Cognitive Acceleration through Science Education and	Search	To evidence a counterargument

Motivational Style: a critique of Adey and Shayer. *International Journal of Science Education, 18*(1), 35-49.		to CASE being an effective strategy for learning Science
McDonald Connor, C., Kaya, S., Luck, M., Toste, J. R., Canto, A., Rice, D., . . . Underwood, P. S. (2010). Content Area Literacy: Individualizing Student Instruction in Second-Grade Science. *The Reading Teacher, 63*(6), 474-485.	Search	To evidence a reading strategy similar to the WM reading sheets as an effective strategy for learning
McLeod, S. (2015). *Piaget*. Retrieved January 21, 2017, from Simply Psychology: http://www.simplypsychology.org/piaget.html	Search	To evidence Piaget's theories of students' learning
McLellan, R. (2006, June 1). The impact of motivation "World-view" on engagement with a cognitive accelleration program. *International Journal of Science Education, 28*(7), 781-819.	Search	To evidence CASE as an effective international strategy for learning
Packiam Alloway, T., & Alloway, R. (2015). *Understanding Working Memory.* London: SAGE Publications Ltd.	Search	To evidence how WM impacted on learning strategy

Panadero, E. (2017, April 28). A Review of Self-regulated Learning: Six Models and Four Directions for Research. *Frontiers in Psychology*, 1-28.	Scattergun	To evidence self-regulated learning as an effective strategy for learning
Piaget, J., & Inhelder, B. (2015 (first published 1973 in English)). *Memory and Intelligence.* Hove: Psychology Press Hove. Retrieved January 25, 2017, from http://lib.myilibrary.com/Open.aspx?id=768137	Search	To evidence Piaget's theories of students' learning in the context of WM
Pilegard, C., & Fiorella, L. (2016, December). Helping students help themselves: Generative learning strategies improve middle school students' self-regulation in a cognitive tutor. *Computers in Human Behavior, 65*, 121-126.	Scattergun	To evidence self-regulated learning as an effective strategy for learning
Rawlings, N. (2015, February). Exercise and the brain. *Biological Sciences Review, 27*(3), pp. 34-37.	Scattergun	To evidence exercise and classroom activities combined as an effective strategy for learning
Sumeraki, M., Nebel, C., Kuepper-Tetzel, C., & Need Kaminski, A. (2021, September 3). *Podcast on Elaborative*	Knew already	To evidence elaborative

Interrogation. Retrieved from Learning Scientists: https://www.learningscientists.org/learning-scientists-podcast/2017/11/1/episode-6-elaborative-interrogation		interrogation as an effective strategy for learning
Venville, G., Oliver, M., & Adey, P. (2012). Effects of a Cognitive Accleration Programme in a Low Socioeconic High School in Regional Australia. *International Journal of Science Education, 34*(9), 1393-1410.	Search (very specific)	To evidence CASE as an effective strategy for learning Science
Willingham, D. T. (2012, Fall). Measured Approach or Mythical Elixir: How to tell good science from bad. *American Educator*, 4-10, 38-40.	Scattergun	To evidence non-evidenced based teaching strategy are often mistakenly used as effective strategies for learning
Willingham, D. T. (2018). Unlocking The Science of How Kids Think: A New Proposal for Reforming Teacher Education. *Education Next*, 42-49.	Scattergun	To evidence non-evidenced based teaching strategy are often mistakenly used as effective strategies for learning

Table 32 The literature included in Section 2.6 of the literature review, the source of the literature and justification for using the literature

Studies Included in Section 2.6 of the Literature Review	Source of Literature	Summary of how this study was useful for Section 2.6 of the Literature Review
Abadzi, H. (2016). TraScaining 21st-century workers: Facts, fiction and memory illusions. *Internation Review of Education, 62*, 253-278.	Scattergun	Evidence to support the argument that not considering WM in the classroom could have an economic impact
	Scattergun	Evidence to support the idea that more research on WM in the classroom is needed
Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance and math anxiety. *Psychonomic Bulletin and Review, 14*(2), 243-248.	Search	Evidence to support the idea that maths anxiety impacts on WM in the classroom
Bryan, R. R., Glynn, S. M., & Kittleson, J. M. (2011, July 25). Motivation, Achievement, and Advanced Placement Intent of High School Students Learning Science. *Science Education*, 1049-1065.	Scattergun	Evidence to support the idea that student motivation could be another strategy to have a similar impact to WM

Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. *Education Psychology Review, 26*, 197-223.	Search	Evidence to support the ideas that WM impacts on intelligence and reading doesn't just tax the WM
Cromley, J. G., Weisburg, S. M., Dai, T., Newcombe, N. S., Schunn, C. D., Massey, C., & Merlino, F. J. (2016, July 5). Improving Middle School Science Reasoning Using Diagrammatic Reasoning. *Science Education, 100*(6), 1184-1213.	Scattergun	Evidence to support the idea that diagrammatic reasoning could improve science attainment without WM being explicitly involved
Dehn, M. J. (2008). *Working Memory and Academic Learning: Assessment and Intervention.* New Jersey: John Wiley & Sons Inc.	Search	Evidence to support the ideas that a busy classroom environment can overload WM & writing will always use WM and never be fully automated
Demetriou, A., Spanoudis, G., Shayer, M., van der Van, S., Brydges, C. R., Kroesbergen, E., . . . Swanson, H. L. (2014). Relations between speed, working memory, and intelligence from preschool to adulthood: Structural equation modelling of 14 studies. *Intelligence, 46*, 107-121.	Search	Evidence to support the idea that WM is linked to intelligence

Duan, X., Wei, S., Wang, G., & Shi, J. (2010). The relationship between executive functions and intelligence on 11- to 12 - year old children. *Psychological Test and Assessment Modelling, 52*(4), 419-431.	Search	Evidence to support the ideas that executive function and self-regulated learning (SRL) are linked, and training executive function will improve SRL and hence attainment
Duncan, L. G., McGeown, S. P., Griffiths, Y. M., Stothard, S. E., & Dobai, A. (2016). Adolescent reading skill and engagement with traditional and digital literacies as predictors of reading comprehension. *British Journal of Psychology, 107*, 209-238.	Scattergun	Evidence to support the ideas that WM is not explicitly linked to reading comprehension
Faust, M. W., Ashcraft, M. H., & Fleck, D. E. (1996). Mathematics Anxiety Effects In Simple and Complex Addition. *Mathematical Cognition, 2*(1), 25-47.	Scattergun	Evidence to support the ideas that maths anxiety is linked students with maths anxiety will do problems quickly rather than get the answers correct
Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualsing Working Memory in Educational Research. *Education Psychology Review, 27*, 333-351.	Search	Evidence to support the ideas that WM becoming overloaded in a busy classroom can

		prevent information being stored in the LTM & that weak reading and writing skills could be linked to not being able to activated the correct part of the LTM rather than WM deficits
Finlayson, M. (2014). Addressing math anxiety in the classroom. *Improving Schools, 17*(1), 99-115.	Scattergun	Evidence to support the ideas that maths anxiety is not linked to WM but to teaching and other strategies
Fleming, K. A., Heintzelman, S. J., & Bartholow, B. D. (2016, June). Specifying Associations Between Conscientiousness and Executive Function: Mental Set Shifting, Not Prepotent Response Inhibition or Working Memory Updating. *Journal of Personality, 84*(3), 348-359.	Search	Evidence to suggest that WM was not linked to conscientiousness and hence was not linked to the attainment of the students
Friedman, N. P., Miyake, A., Corley, R. P., Young, S. E., DeFries, J. C., & Hewitt, J. K. (2006). Not All Executive Functions Are Related to Intelligence. *Psychological Science, 17*(2), 172-179.	Search	There is conflicting evidence that tends towards updating and shifting (EF) not being closely linked to Gf

Graham, S., Kiuhara, C. A., & MacKay, M. (2020, April). The Effects of Writing on Learning in Science, Social Studies and Mathematics: A Meta-Analysis. *Review of Educational Research, 90*(2), 179-226.	Search	Evidence to support students writing about science improved attainment with no link to WM
Hassed, C., & Chambers, R. (2014). *Mindful Learning.* Aukland, New Zealand: Exisle Publising Ply LTD.	Scattergun	Evidence to support the link between WM, LTM and EF & that learning cannot take place unless there is sufficient WM capacity & that the ability to do task shifting comes at the cost of being less able to focus on one task
Kellogg, R. T. (2001). Competition for working memory among writing processes. *American Journal of Psychology, 114*(2), 175-191.	Search	Evidence to support that WM is used to plan & review writing tasks, used in imagery when writing & there is a link between WM capacity and being able to read or write

Kirschner, P., & De Bruyckere, P. (2017). The myths of the digital native and the multitasker. *Teaching and Teacher Education, 67*, 135-142.	Scattergun	Provided evidence to state that there is little evidence to support the idea that students are multitasking digital natives
Kirstein, S., Wersing, H., & Korner, E. (2008). A biologically motivated visual memory architecture for online learning of objects. *Neural Networks, 21*, 65-77.	Scattergun	Evidence to support when LTM is viewed with a Biologically motivated approach that students focus is effective at storing information in the LTM without WM models being used
Le Bigot, N., Passerault, J.-M., & Olive, T. (2012). Visuospatial Processing in Memory for Word Location in Writing. *Experimental Psychology, 59*(3), 138-146.	Scattergun	Evidence to support once students have composed and completed a piece of writing a visual representation of the text seems to be stored in visual WM

Lechuga, M. T., Pelegrina, S., Pelaez, J. L., Martin-Puga, M. E., & Justicia, M. J. (2014). Working memory updating as a predictor of Academic Attainment. *Educational Psychology*, 675-690.	Search	Evidence to support WM, updating (EF) and Gf are closely linked
McLeod, S. (2015). *Piaget*. Retrieved January 21, 2017, from Simply Psychology: http://www.simplypsychology.org/piaget.html	Search	Evidence to support if the student has no prior knowledge of this new information, then they will have to start building a new schema
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variables Analysis. *Cognitive Psychology, 41*, 49-100.	Search	Evidence to support the link between WM, LTM and executive function
Olinghouse, N. G. (2008). Student- and instruction-level predictors of narrative writing in third grade students. *Reading and Writing, 21*, 3-26.	Scattergun	Evidence to suggest WM is not linked to reading comprehension or writing ability
Olive, T. (2004). Working Memory in Writing: Empirical Evidence From the Dual-Task Technique. *European Psychologist, 9*(1), 32-42.	Search	Evidence to support phonological loop (a part of the Baddeley and Hitch WM model) is

		also involved in the planning process of writing
Prain, V., Waldrip, B., Sbaglia, R., & Lovejoy, V. (2017, March). Towards personalising learning in school science: Making this learning more relevant. *Teaching Science, 63*(1), 27-33.	Search	Evidence to suggest that it is making the Science curriculum personal to the student's lives that improves attainment and not developing WM
Reynolds, C. R., & Voress, J. K. (2007). *TOMAL 2 Test of Memory and Learning : Examiner's Manuel* (2nd ed.). Austin, Texas, USA: PRO-ED Inc.	From SEND expert where I work	Used as an example of general cognitive assessment to ascertain the if a student has learning difficulties including WM deficits
Service, E., & Turpeinen, R. (2001). Working memory in spelling: Evidence from backward typing. In S. E. Gathercole (Ed.), *Short-term and Working Memory* (Vol. 9, pp. 395-421). Hove: Psychology Press.	Search	Evidence to suggest WM is needed for spelling an important part of planning and writing
Swanson, H. L., & Berninger, V. W. (1996). Individual Differences in Children's Working Memory and Writing Skill. *Journal of Experimental Child Psychology, 63*, 358-385.	Search	Evidence to support writing ability of people is linked to their WM

Teng, F. (., & Huang, J. (2019). Predictive Effects of Writing Strategies for Self-Regulated Learning on Secondary School Learners' EFL Writing Proficiency. *Tesol Quarterly*, 232-247.	Scattergun	Evidence to support SRL has a positive relationship with writing strategies and writing ability in Secondary School students where researchers made no link between SRL and EF or WM
Vanderberg, R., & Swanson, H. L. (2007). Which Components of working memory are important in the writing process? *Read Writ, 20*, 721-752.	Search	Evidence to suggest two other parts of the WM ie visuo-spatial sketch pad* and the phonological loop* did not predict any of the writing skills (*parts of WM in Baddeley and Hitch Model)
Wang, C.-L., & Liou, P.-Y. (2017). Students' motivational beliefs in science learning, school motivational contexts and science achievement in Taiwan. *International Journal of Science Education, 39*(7), 898-917.	Search	Evidence to support it is student motivation and not WM that has an impact on science attainment

Table 33 The literature included in Section 2.7 of the literature review, the source of the literature and justification for using the literature

Literature	Search	Summary of how this study was useful for Section 7 of the Literature Review
Affes, S., Borji, R., Zarrouk, N., Sahli, S., & Rebai, H. (2021). Effects of running exercises on reaction time and working memory in individuals with intellectual disability. Journal of Intellectual Disability Research, 91-112.	Search	Evidence to support the idea that physical exercise can improve EF & hence possibly attainment in school
Au, J., Buschkuehl, M., Duncan, G. J., & Jaeggi, S. M. (2016). There is no convincing evidence that working memory training is NOT effective: A reply to Melby-Lervag and Hulme (2015). Psychonomic Bulletin and Review, 23, 331-337.	Search	Evidence to answer critique of meta-analysis that concluded that WM significantly increases intelligence
Banks, J. B., Wellhaf, M. S., & Srour, A. (2015). The protective effects of brief mindfulness meditation training. Consciousness and Cognition, 277-285.	Scattergun	Evidence to support the idea that mindfulness can protect against the impact of stress on WM
Buschkuehl, M., Jaeggi, S. M., Hutchinson, S., Perrig-Chiello, P., Dapp, C., Muller, M., . . . Perrig, W. J. (2008). Impact of Working	Search	Evidence to suggest that WM training works in adults who are 80 years and older

Memory Training on Memory Performance in Old-Old Adults. Psychology and Aging, 23(4), 743-753.		
Cooper, S. J. (2005). Donald O. Hebb's synapse and learning rule: a history and commentary. Neuroscience and Biobehavioural Reviews, 28, 851-874.	Scattergun	Evidence to support the idea that brain plasticity was only present in embryo and infant stages of brain development. To show early ideas of neuroplasticity that have now be disproven.
Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. Education Psychology Review, 26, 197-223.	Search	Evidence to support that WM is fixed and that other mechanisms are at play that are making WM more efficient that are linked to how the LTM stores chunks of information
Dehn, M. J. (2008). Working Memory and Academic Learning: Assessment and Intervention. New Jersey: John Wiley & Sons Inc.	Search	Evidence to support that the visual sketch pad from Baddeley and Hitch WM model was linked to physical activity & that WM can become more efficient rather than larger
Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive	Scattergun	Evidence to support the idea that WM training has been linked to exercise &

functions that appear justified and those that, despite much hype, do not. Developmental Cognitive Science, 18, 34-48.		mindfulness. A lot of WM Computer training is used. There is an optimum training time and if training is not maintained then WM activity can decrease again
Dobbs, D. (2007). Erik Kandel: From Mind to Brain and Back Again. Scientific American Mind, 18(5), 32-37.	Scattergun	Evidence to support that there are physical changes in the brain and memory that are linked to emotions
Ericsson, A. K., Delaney, P. F., Weaver, G., & Mahadevan, R. (2004). Uncovering the structure of a memorist's superior "basic" memory capacity. Cognitive Psychology, 49, 191-237.	Scattergun	Evidence to support the idea that memorisation can be trained to an expert level
Farina, M. (2017). Neural Plasticity: Don't Fall For All The Hype. British Academy Review, 54-56.	Search	Evidence to support the idea that the positive gains from brain training can be explained in other areas of psychology and not by neuroplasticity
Halpern, D. F. (1998, April). Teaching Critical Thinking for Transfer Across Domains: Depositions, Skills, Structure Training, and Metacognitive Monitoring. American Psychologist, 449-456.	Scattergun	Evidence to support the idea that students can be trained to use their critical thinking ability (as a way to better use

		the WM capacity they already have)
Jha, A. P., Stanley, E. A., Kiyonaga, A., Wong, L., & Gelfand, L. (2010). Examining the Protective Effects of Mindfulness Training on Working Memory Capacity and Affective Experience. Emotion, 10(1), 54-64.	Search	Evidence to support the idea that WM training can reduce stress levels
Kandel, E. (2005). Erik Kandel: The Future of Memory (an interview with Erik Kandel). Molecular Interventions, 65-68.	Scattergun	Evidence to support that there are physical changes in the brain and memory that are linked to emotions. We also do not know all the parts of the brain involved with memory, and how the interact with each other including WM and LTM
Lee, Y.-s., Lu, M.-j., & Ko, H.-p. (2007). Effects of skill training on working memory capacity. Learning and Instruction, 17, 336-344.	Search	Evidence to support the idea that learning music can have a positive effect on WM, as can doing mental arithmetic
Martinie, M.-A., Olive, T., & Milland, L. (2010). Cognitive dissonance induced by writing a counterattitudial essay facilitates performance on simple tasks but not on complex tasks that involve working memory.	Search	Evidence to support the idea that cognitive dissonance taxes the WM, leading to tasks that need WM to be completed less well

Journal of Experimental Social Psychology, 46, 587-594.		
McNeil, F. (2009). Learning with the Brain in Mind. London: SAGE Publications LTD.	Already had this book	Evidence to support neuroplasticity training can improve the size of the brain e.g., using imagination, mental rehearsal, stroke patients recovering using a specific technique, the thoughts people have, meditation and exercise. Attention focus is important for neuroplasticity
Melby-Lervag, M., & Hulme, C. (2016). There is no convincing evidence that working memory is effective: A reply to Au et al. (2014) and Karbach and Verhaegen (2014). Psychonomic Bulletin Review, 23, 324-330.	Search	Evidence to critique the idea that WM training can significantly improve intelligence
Randall, L., & Tyldesley, K. (2016). Evaluating the impact of working memory. Educational & Child Psychology, 33(1), 34-50.	Search	Evidence to support the idea that it is not clear if WM training is increasing the size or efficiency of the WM
Renshaw, I., Davids, K., Araujo, D., Lucas, A., Roberts, W. M., Newcombe, D. J., & Franks, B. (2019, January). Evaluating Weaknesses of "Perceptual-cognitive Training" and "Brain	Scattergun	Evidence to support the idea that in some sports there was little evidence that this helped improve WM

Training" Methods in Sport: An Ecological Dynamics Critique. Frontiers in Psychology, 9, 1-12.		
Ricard, M. (2007). Happiness: A guide to developing life's most important skill. London, UK: Atlantic Books: An Imprint of Atlantic Grove LTD.	Already had the book	Evidence to support the idea that neuroplasticity as a scientifically observed fact has become more widely accepted over the past 30 years
Smicker, M., Schwefel, M., Vellage, A.-K., & Muller, N. G. (2016). Training of Attentional Filtering, but Not of Memory Storage, Enhances Working Memory Efficiency by Strengthening the Neuronal Gatekeeper Network. Journal of Cognitive Neuroscience, 636-642.	Scattergun	Evidence to support the idea that brain training increased the efficiency of the neuronal gatekeeper network in the prefrontal lobe that is associated with the WM
Wass, S. V. (2015). Applying cognitive training to target executive functions during early development. Child Neuropsychology, 21(2), 150-166.	Scattergun	Evidence to support the idea that children as young as 11 months demonstrated improved WM function after WM training
Wass, S., Parayska-Pomsta, K., & Johnson, M. H. (2011, September 27). Training Attentional Control in Infancy. Current Biology, 21, 1543-1547.	Scattergun	Evidence to support the idea that children as young as 11 months demonstrated improved WM function after WM training

Table 34 The literature included in Section 2.8 of the literature review, the source of the literature and justification for using the literature

Literature	Search	Summary of how this study was useful for Section 2.8 of the Literature Review
Alloway, T. P., & Gathercole, S. E. (2009). Working Memory and Learning: A Practical Guide for Teachers. London: SAGE Publications.	Search	Evidence to support the idea that underachievement is linked to weak WM or weak WM in combination with another learning disability. This is seen in maths, English and Science. Also, that student performance on WM tests predicts underachievement
Berninger, V. W., Abbott, R. D., Swanson, H. L., Lovitt, D., Trivedi, P., Lin, S.-J.; Amtmann, D. (2010). Relationship of Word- and Sentence-Level Working Memory to Reading and Writing in Second, Fourth, and Sixth Grade. Language, Speech, and Hearing Services in Schools, 41, 179-193.	Search	WM is a good predictor of reading comprehension
Boudreau, D., & Contanza-Smith, A. (2011). Assessment and Treatment of Working Memory Deficits in School Age Children: The Role of the Speech and Language Pathologist. Language,	Search	Evidence to support the idea that students with language impairments could struggle in part because of a weak WM in attention, processing and storage of information

speech and hearing services in Schools, 42, 152-166.		
Carden, J., & Cline, T. (2015). Problem solving in mathematics: the significance of visualisation. Educational Psychology in Practice, 31(3), 235–246.		Evidence to support the idea that students in early years use more WM (WM more heavily taxed) when doing maths compared to older years (unless in the latter it is a complex word maths problem)
Carretti, B., Re, A. M., & Arfe, B. (2013). Reading Comprehension and Expressive Writing: A comparison between good and poor comprehenders. Journal of Learning Disabilities, 46(1), 81-96.	Scattergun	Evidence to support the idea narratives could overload WM. In the WM updating task, poor comprehenders seemed to perform worse than good comprehenders
Cowan, N. (2014). Working Memory Underpins Cognitive Development, Learning, and Education. Education Psychology Review, 26, 197-223.	Search	Evidence to support the idea that writing not only taxes WM but also LTM also differentiation can be used to support students with WM deficit
Daneman, M., & Carpenter, P. A. (1980). Individual Differences in Working Memory and Reading. Journal of Verbal Learning and Verbal Behavior, 19, 450-466.	Search	Evidence to support the idea that people who have become better at a cognitive task may have done so because they have developed a larger WM capacity as a result of their practicing & the predictive effect of WM could be to some degree domain specific

Dehn, M. J. (2008). Working Memory and Academic Learning: Assessment and Intervention. New Jersey: John Wiley & Sons Inc.	Search	Evidence to support the idea that EF deficit and verbal WM deficit, some researchers have attributed this to a WM capacity deficit whereas others state that there is a lack of learned strategies in students with learning disabilities & Most researchers agree that the individual differences in peoples' WM can mostly be contributed to the processing ability of the central executive. Students with learning disabilities with a WM deficit found complex maths problems more difficult. Also, verbal WM is a differentiator for reading level and reading comprehension. Also, visuospatial WM impact on reading is not well researched and other factors could impact on reading skills. Also, differentiation to support students with WM deficit
Duncan, L. G., McGeown, S. P., Griffiths, Y. M., Stothard, S. E., & Dobai, A. (2016). Adolescent reading skill and engagement with traditional and digital literacies as predictors of reading comprehension. British Journal of Psychology, 107, 209-238.	Scattergun	Evidence to support the idea that age, gender and frequency of reading traditional texts is a differentiator of reading ability in adolescents

Engle, R. D., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working Memory, Short-Term Memory, and General Fluid Intelligence: A Latent Variable Approach. Journal of Experimental Psychology: General, 128(3), 309-331.	Search	Evidence to support the idea that WM and STM work independently of each other
Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualising Working Memory in Educational Research. Education Psychology Review, 27, 333-351.	Search	Evidence to support the idea that not being able to inhibit information effectively would have an impact on mathematics attainment; students with weak or poor writing skills this could be caused by not being able to activate the correct information in the LTM rather than just WM deficits.
Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working Memory Skills and Educational Attainment: Evidence from National Curriculum Assessments at 7 and 14 Years of Age. Applied Cognitive Psychology, 18, 1-16.	Search	One of a number of research teams that have investigated the differentiating effect of WM on attainment in Mathematics and English. Evidence to support the idea that WM seems to be a differentiator of academic performance in Mathematics, English and Science in England; however English Literature KS3 SATS independent of WM
Giofre, D., Mammarella, I. C., & Cornoldi, C. (2014). The relationship	Search	Evidence to support idea that Academic achievement in geometry seems to have a

among geometry, working memory, and intelligence in children. Journal of Experimental Child Psychology, 123, 112-128.		large dependency on WM Intuitive geometry is closely related to fluid intelligence and intuitive geometry is not linked to academic achievement in geometry.
Gropen, J., Clark-Chiarelli, N., Hoisington, C., & Ehrlich, S. B. (2011). The Importance of Executive Function in Early Science Education. CHILD DEVELOPMENT PERSPECTIVES, 5(4), 298–304.	Scattergun	Evidence to support the idea that EF being a differentiator of Early Science education
Henry, L. A. (2001). How does the severity of a learning disability affect working memory performance? In S. E. Gathercole (Ed.), Short Term and Working Memory (Vol. 9, pp. 233-247). Hove: Psychology Press.	Scattergun	Evidence to support the ideas that students with very minor learning disabilities have a phonological WM deficit, whereas students with minor to moderate learning disabilities have WM deficits in all constructs of WM
Just, M. A., & Carpenter, P. A. (1992). A Capacity Theory of Comprehension: An individual differences in Working Memory. Psychological Review, 99(1), 122-149.	Search	Evidence to support the idea that WM processing efficiency is weak the overall performance of the individual WM will have a negative impact on their ability to comprehend reading and compose writing
Kornmann, J., Zettler, I., Kammerer, Y., Gerjets, P., & Trautwein, U. (2015). What characterizes children nominated as gifted by teachers? A	Search	Evidence to support the idea that WM is having an impact on student achievement and other characteristics that teachers look

closer consideration of working memory and intelligence. High Ability Students, 26(1), 75-92.		for in Gifted and Talented students such as reading comprehension and verbal abilities
Lechuga, M. T., Pelegrina, S., Pelaez, J. L., Martin-Puga, M. E., & Justicia, M. J. (2014). Working memory updating as a predictor of Academic Attainment. Educational Psychology, 675-690.	Search	Evidence to support the idea that WM updating EF is a good predictor of academic attainment, especially when using numerical based activities
Matthews, E., & Adlam, A. (2015, November 21). Working memory, attentional control and mathematics performance in moderate to late preterm children - implications for intervention. Personal Correspondence to Parent.	Scattergun	Evidence to support the idea that children who are rated highly for thinking before acting and sitting still by their parents did better in the maths tests this could be because they can access the teaching more effectively
McGowan, M. R., Holtzman, D. R., Coyne, T. B., & Miles, K. L. (2016). Predictive Ability of the SB5 Gifted Composite Versus the Full-Scale IQ Among Children Referred for Gifted Evaluation. Roeper Review, 38, 40-49.	Scattergun	Evidence to support the idea that WM measures in IQ tests for Gifted and Talented students the WM part correlates strongly with the reading comprehension outcomes but not the Mathematics

Olinghouse, N. G. (2008). Student- and instruction-level predictors of narrative writing in third grade students. Reading and Writing, 21, 3-26.	Scattergun	Evidence to support the idea that student characteristics including gender, being able to plan the writing in advance, IQ and fluidity of hand writing are differentiators of writing ability (argument found doesn't involve WM)
Packiam Alloway, T., & Alloway, R. (2015). Understanding Working Memory. London: SAGE Publications Ltd.	Search	Evidence to support the ideas that WM seems to be a differentiator of academic performance in Mathematics, English and Science in England, many different learning disabilities have a WM deficit, students who have dyscalculia have a weak WM due to poorer functioning prefrontal cortex, in the classroom differentiation may be used to support students with WM deficit,
Peng, P., & Fuchs, D. (2016). A Meta-Analysis of Working Memory Deficits with Children with Learning Difficulties: Is there a difference between verbal domain and numerical domain? Journal of Learning Disabilities, 49(1), 3-20.	Search	Evidence to support the ideas that WM is the differentiator of attainment for students with learning disabilities in Mathematics; students with moderate disabilities have the largest weakness in numerical WM. However, this may be due to the lack of mathematical knowledge in LTM rather than a WM deficit
Peng, P., Namkung, J., Barnes, M., & Sun, C. (2015, September 7). A Meta-Analysis of Mathematics and	Search	Evidence to support the idea that WM was a better differentiator of students with poorer

Working Memory: Moderating Effects of Working Memory Domain, Type of Mathematics Skill, and Sample Characteristics. Journal of Educational Psychology, 1-19.		mathematical skills than other ability students
Pimperton, H., & Nation, K. (2014). Poor Comprehenders in the Classroom: Teacher Ratings of Behaviour in Children With Poor Reading Comprehension and Its relationship with Individual Differences in Working Memory. Journal of Learning Disabilities, 47(3), 199-207.	Search	Evidence to support the ideas that verbal WM is a differentiator for reading level and reading comprehension; & a small proportion of people also present with behaviours linked to overall WM weakness which attribute to a domain general WM weakness
Riding, R. J., Grimley, M., Dahraei, H., & Banner, G. (2003). Cognitive style, working memory and learning behaviour and attainment in school subjects. British Journal of Educational Psychology, 73, 149-169.	Search	Evidence to support the idea that cognitive styles research the evidence tends towards WM being a differentiator for academic attainment in Science; WM was a significant differentiator of Year 8 (12–13-year-olds) students' Science attainment
Shaywitz, S. E., Shaywitz, B. A., Fulbright, R. K., Skudlarski, P., Einar, M. W., Constable, T., . . . Gore, J. C. (2003). Neural Systems for Compensation and Persistence:	Scattergun	Evidence to support the idea that dyslexic students may have more blood going to the prefrontal cortex compared to normal students

Young Adult Outcome of Childhood Reading Disability. Biological Psychiatry, 54, 25-33.		
Swanson, H. L., & Berninger, V. W. (1996). Individual Differences in Children's Working Memory and Writing Skill. Journal of Experimental Child Psychology, 63, 358-385.	Search	Evidence to support the ideas that WM tests that include processing and verbal storage (both linked to WM) seem to be good predictors for students to be able to comprehend text; WM is the differentiator of attainment for students with learning disabilities in Reading, Writing
Swanson, H. L., Zheng, X., & Jerman, O. (2009). Working Memory, Short-Term Memory, and Reading Disabilities: A Selective Meta-Analysis of the Literature. Journal of Learning Disabilities, 42(3), 260-287.	Search	Evidence to support the ideas that reading weakness may be in the phonological loop and the executive system and seems to continue with age; there being a relationship between STM, WM or IQ.
Unknown. (2018, April 23). Do Brain Training Apps Really Work? Retrieved from FYK Technology: https://fykmobile.com/articles/brain-tranning.html	Scattergun	Evidence to support the idea that scepticism should be used when looking at the idea of WM testing to predict academic performance as it could be a big money-making scheme
Wass, S. V. (2015). Applying cognitive training to target executive functions during early development. Child Neuropsychology, 21(2), 150-166.	Scattergun	Evidence to support the idea that a link between early years students with chromosomal disorders having attentional

		control/WM deficits that go on to lead to more complex learning disabilities

Table 35 The literature included in Section 2.9 of the literature review, the source of the literature and justification for using the literature

Literature	Search	Summary of how this study was useful for Section 9 of the Literature Review
Apter, B. J. (2012). Do computerised training programmes designed to improve. Educational Psychology in Practice, 28(3), 257-272.	Search	Evidence to support the ideas that: there is WM training in school age children; WM training must have differentiation which enables work to be challenging and yet accessible is so important; testing the different components of WM were criticised for not being rigorous or specific enough and also again the lack of active control groups, WM training programs are both time consuming and economically very expensive

Aries, R. J., Groot, W., & van den Brink, H. M. (2015). Improving reasoning skills in secondary. British Educational Research Journal, 41(2), 210–228.	Scattergun	Evidence to support the idea that an increase in the WM and reasoning skills of students, may also be used to increase attainment when delivering History to secondary school students
Carretti, B., Cardarola, N., Tencati, C., & Cornoldi, C. (2014). Improving reading comprehension in reading and listening settings: The effect of two training programmes focusing on metacognition & working memory. . British Journal of Educational Psychology, 84, 194-210.	Search	Evidence to support the idea that training focused on WM and metacognitive processes in reading had a bigger impact than the training focused on WM and metacognitive processes in a listening group; primary school student's arithmetic problem-solving skills improved
Cornoldi, C., Carretti, B., Drusi, S., & Tencati, C. (2015). Improving problem solving in primary school. British Journal of Educational Psychology, 85, 424-439.	Scattergun	Evidence to support the idea that group who did the training earliest in the school year also maintained the gains made in WM and metacognition after the training had finished

Dehn, M. J. (2008). Working Memory and Academic Learning: Assessment and Intervention. New Jersey: John Wiley & Sons Inc.	Search	Evidence to support the idea that It is important to encourage students to use it (WM training) in domain specific ways when applying their training or no far transfer or even near transfer will be evident
Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. Developmental Science, 12(4), F9-F15.	Search	Evidence to support ideas that WM training in school age children research is happening; WM training seems to have the biggest impact for those students who start out with the lowest WM; published studies have included academically “normal” students as well as students who have a range of learning disabilities: WM training students with low WM appear to increase in their maths attainment after 6 months

Karbach, J., Strobach, T., & Schubert, T. (2015). Adaptive working-memory training benefits reading, but not mathematics in middle school. Child Neuropsychology, 21(3), 285-301.	Search	Evidence to support ideas that WM training academically "normal" students as well as students who have a range of learning disabilities is happening; no evidence that the adaptive WM training improves performance in the standardised math test; biggest compensation made with the lowest scoring pre-test WM students showed the biggest transfer effects;
Klinberg, T. (2010). Training and plasticity of working memory. Trends in Cognitive Science, 14, 317-324.	Search	Evidence to support the ideas that WM training seems to have the biggest impact for those students who start out with the lowest WM; WM training could support students with low WM and to improve academic attainment
Randall, L., & Tyldesley, K. (2016). Evaluating the impact of working memory.	Search	Evidence to support the idea that delivering WM training on the computer could limit the potential for WM training in

Educational & Child Psychology, 33(1), 34-50.		school aged students; transfer effects observed in WM training studies are with small samples etc and effects could be caused by other factors
St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. Educational Psychology, 30(2), 203–219.	Search	Evidence of teams doing WM training in school age children. Evidence to support the ideas that WM training increased the WM of the students involved; it is hard to discern if *Memory Booster* is having an impact on WM capacity or the strategies are making the WM more efficient; Nor was there any far transfer found in test results in class using *Memory Booster*
Titz, C., & Karbach, J. (2014). Working memory and executive functions: effects of training on academic achievement. Psychological Research, 78, 852-868.	Search	Evidence to support the ideas WM training has shown improvements in literacy, improvements have been reported for healthy children and those with cognitive deficits and learning

		disabilities; rather than using general WM (EF) training regimes a more appropriate approach would be domain-specific training;
Van de Sande, E., Segers, E., & Verhoeven, L. (2016). Supporting executive functions during children's preliteracy learning with computer. Journal of Computer Assisted Learning, 32, 468-480.	Scattergun	Evidence to support the ideas that WM training increased the WM of the students; positive results are all in terms of being more independent and playing more games in this independent manner (on WM training on computers); no near transfer to literacy skills was found in the classroom
Van der Molen, M. J., Van Luit, J. E., Van der Molen, M. W., Klugkist, I., & Jongmans, M. (2010). Effectiveness of a computerised working memory in adolescents with mild to borderline intellectual disabilities. Journal of Intellectual Disability Research, 54(5), 433-447.	Search	Evidence to support the ideas that could be possible to improve the WM of students; both adaptive and non-adaptive computerised WM training had a positive impact on story recall, arithmetic, and visual STM; adaptive WM computerised training have

		been used with both primary and secondary students.

Table 36 The literature included in Section 2.11 of the literature review, the source of the literature and justification for using the literature

Literature	Search	Summary of how this study was useful for Section 10 of the Literature Review
Adesope, O. O., Trevisan, D. A., & Sundararajan, N. (2017, June). Rethinking the Use of Tests: A Meta-Analysis of Practice Testing. Review of Educational Research, 87(3), 659–701.	Scattergun	A counterargument against neuro science in the classroom using the evidence-based strategies such as retrieval practice instead
Bierman, K. L., Nix, R. L., Greenberg, M. T., Blair, C., & Domitrovich, C. E. (2008). Executive functions and school readiness intervention: Impact, moderation, and mediation in the Head Start REDI program. Development and Psychopathology, 20, 821-843.	Search	Evidence to support the idea of REDI intervention delivered by especially trained teachers in classrooms; & it has not had a direct impact on WM

Bruer, J. T. (1997, November). Education and the Brain: A Bridge Too Far. Educational Researcher, 26(8), 4-16.	Scattergun	the counterargument against neuro science in classroom and using cognitive psychology to inform pedagogical changes in the classroom instead
Cunningham, J., & Sood, K. (2016). How effective are working memory training interventions at improving maths in schools: a study into the efficacy of working memory training in children aged 9 and 10 in a junior school? Education 3-13, 1-14.	Search	Cunningham amongst other researchers' evidence to support the idea that WM training research conducted within a school setting
Dehn, M. J. (2008). Working Memory and Academic Learning: Assessment and Intervention. New Jersey: John Wiley & Sons Inc.	Search	Evidence to support the idea that students completing short-term standalone intervention do not show long term transfer effects on students
Diamond, A. (2010). The Evidence Base for Improving School Outcomes by Addressing the Whole Child and Addressing Skills and	Scattergun	Evidence to support the idea that stress affects WM (EF) negatively

Attitude, Not just content. Early Education and Development, 780-795.		
Diamond, A. (2011). Activities and Programs that improve Children's Executive Functions. Current Directions in Psychological Science, 21(5), 335-341.	Search	Evidence to support the idea that students may show improvements in their WM (EF) that authors of studies or administrators or creators of these programmes may claim were down to the structure of the intervention
Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. Developmental Cognitive Science, 18, 34-48.	Search	Tools of the Mind was an intervention used to train WM. Evidence to support the ideas that when integrated into the classroom activities as part of the normal routine of teaching much better WM (EF) far transfer effects appear to have been demonstrated; there are many factors however that could be impacting on student attainment; The improvements seen from such interventions as Tools of the

		Mind, Take10!® and CogMed® might well be due to the passion and commitment of the person or people running the intervention; the more committed the people supporting the participants are then the more likely the intervention will succeed
Dougherty, M. R., & Robey, A. (2018). Neuroscience and Education: A Bridge Astray. Current Directions in Psychological Science, 27(6), 401-406.	Scattergun	Evidence to support the ideas that neuroscience not being able to transfer into effective teaching strategies and furthermore, an opinion that there was little evidence to support the efficacy of brain training research; brain training and neuroscience in the classroom not being effective
Farina, M. (2017). Neural Plasticity: Don't Fall For All The Hype. British Academy Review, 54-56.	Search	Evidence to support critique of neuro science/brain training in the classroom

Halpern, D. F., Millis, K., Graesser, A. C., Butler, H., Forsyth, C., & Cai, Z. (2012). Operation ARA: A Computerised learning game that teaches critical thinking and scientific reasoning. Thinking Skills and Creativity, 7, 93-100.	Scattergun	Evidence to support the idea that WM training research conducted within a school setting & alternative computerised training program called Operation Acquire Research Acumen (ARA) that claimed to increase students scientific thinking skills and increase their attention focus
Holmes, J., & Gathercole, S. E. (2014). Taking working memory training from the laboratory into schools. Educational Psychology, 34(4), 440-450.	Search	Evidence to support the ideas that WM training research conducted within a school setting; teacher led WM training would have the same results as "tightly controlled research studies in which the training is implemented by experienced researchers"; WM training saw students achieved significantly greater progress in Maths and English
Howard-Jones, P. (2014). Neuroscience and Education: A	Scattergun (knew of EFF)	Evidence to support the idea that a review of the evidence

Review of Educational Interventions and Approaches Informed by Neuroscience Full Report and Executive Summary. The University of Bristol on behalf of the Education Endowment Foundation, Graduate School for Education. Millbank: Education Endowment Foundation.		supported the view that any effects from brain training interventions were limited only to similar activities and hence only near transfer effects
Kibbe, D. L., Hackett, J., Hurley, M., McFarland, A., Godburn Schubert, K., Schultz, A., & Harris, S. (2011). Ten Years of TAKE 10! :Integrating physical activity with academic concepts in elementary classrooms. *Preventative Medicine*, S43-S50.	Scattergun	Evidence to support the idea that TAKE 10! Has a positive impact on student attainment
Raver, C., Jones, S., Li-Grining, C., Zhai, F., Bub, K., & Pressler, E. (2011, January/February). CSRP's Impact on Low-Income	Scattergun	Evidence supports the impact of an intervention that used WM training; Chicago School Readiness Project (CSRP) an

Pre-schooler's Preacademic Skills: Self-Regulation as a Mediating Mechanism. Child Development, 82(1), 362-378.		effective intervention for pre-schoolers that improves self-regulation.
Riggs, N., Greenberg, M., Kusche, C., & Pentz, M. A. (2006, March). The Mediational Role of Neurocognition in the Behavioural Outcomes of a Social-Emotional Prevention Program in Elementary School Students: Effects of the PATHS Curriculum. Prevention Science, 7(1), 91-102.	Scattergun	Evidence to support the impact of an intervention that used WM training; Promoting Alternate Thinking Strategies (PATHS) a curriculum aimed at changing the challenging behaviour of students by developing EF including WM

Table 37 The literature included in Section 2.10 of the literature review, the source of the literature and justification for using the literature

Literature	Search	Summary of how this study was useful for Section 10 of the Literature Review
Baddeley, A. D., & Hitch, G. (1974). In G. H. Bower, & G. H. Bower (Ed.). London: Academic Press.	Search	Evidence to support the idea of the Baddeley and Hitch WM model
Dignath, C., & Gerhard, B. (2008). Components of fostering self-regulated learning amongst students. A meta-analysis on intervention studies at primary and secondary school level. Metacognition Learning, 231-264.	Scattergun	Evidence to support quantitative data gathering methods have been used previously and so support the justification of theoretical assumptions to use quantitative data in my research particularly where metacognition has been researched previously
Fenesi, B., Sana, F., Kim, J. A., & Shore, D. I. (2015). Reconceptualsing Working Memory in Educational Research. *Education Psychology Review, 27*, 333-351	Search	Using the Baddeley and Hitch model of WM as a framework for their research with school aged students. Justifying this model as measurable and linking to learning.

		How other models are linked to EF and attention focus but are difficult to measure and more challenging to link to learning in a quantitative way.
Hattie, J. A. (2009). Visible Learning: A synthesis of over 800 meta-analysis relating to achievement. Abingdon, Oxon, England: Routledge.	Knew of this book pre-PhD	Evidence to support data gathering methods on changes to LTM/learning and intelligence as these have been used previously and so support the justification of theoretical assumptions to use data in my research particularly where memory, intelligence and learning have been researched previously
Petty, G. (2009). Evidence Based Teaching (2nd ed.). Cheltenham, United Kingdom: Nelson Thornes LTD.	Knew of this book pre-PhD	Evidence to support data gathering methods on changes to LTM/learning and intelligence as these have been used previously and so support the justification of theoretical assumptions to

		use data in my research particularly where memory, intelligence and learning have been researched previously
St Clair-Thompson, H., Stevens, R., Hunt, A., & Bolder, E. (2010). Improving children's working memory and classroom performance. Educational Psychology, 30(2), 203–219.	Search	Evidence to support the idea that WM assessment used in this research was developed by a researcher who uses Baddeley and Hitch model in their research; WM training has improved attainment in students; this was also used to justify the theoretical assumptions of my research questions relating to WM and LTM
St. Clair-Thompson, H. (2015, February). Lucid Recall. Lucid Recall. G L Assessment. Retrieved from https://www.gl-assessment.co.uk/products/lucid-recall/	Knew from finding WM assessment	Evidence to support the idea that WM assessment used in this research was developed by a researcher who uses Baddeley and Hitch model in their research

Appendix B: Method and Methodology: An introduction to WM Tests, an analysis of WM Tests and justification of using or not using WM Tests that were taken into account

Introduction to Appendix B

Appendix B contains information and WM tests, and an analysis of their suitability to be used for WM research in schools. Then more specifically addresses the suitability of the WM tests for use with this PhD thesis.

Introduction to working memory tests

The single biggest challenge this research study faces was finding a cost effective, efficient and rigorous way to measure the WM of students before, during and at the end of the research study. There are currently very few packages that can be used to specifically test for WM of KS3 students. The alternatives were to use a cross battery of WM tests from intelligence tests (Dehn, 2008), or design WM tests specifically for the research or to source WM tests that were available from open sources that other researchers have used (Stone & Towse, 2015).

The Cattell Horn Carroll Intelligence theory is the theory that incorporates memory factors. However, it does have an outdated assumption that WM is a subset of STM and this must be kept in mind when referring to this research paradigm. There are Global and Factor scores that are made for intellectual and cognitive scales which show whether a test has an acceptable level of reliability. However, as WM tests are only subtests the reliability coefficient of the subtest should be examined. If the user of the subtest is going to be able to use the subtest reliably it should have a coefficient of ≥ 0.90. However, subtests rarely have a coefficient that high so a compromise has to made of using tests with a coefficient of ≥0.80; less than this and the subtest should be used alongside another subtest that measures the same aspect of WM. If the subtest has a reliability coefficient of ≤ 0.70 then the subtest should not be used and another subtest should be used in its place (Dehn, 2008).

Working Memory Tests

There was the distinct possibility that conducting the tests outlined in Tables 38 & 39 (p. 392 & 394) would not be possible due to time constraints or cost. For example, the test used with students who may need Exam Access Arrangements for the Joint Council of Qualifications is the TOMAL -2. This is the go-to test for educational psychologists and trained staff in schools to assess students' memory. However, it only gives detailed information on students non-verbal and verbal memory not specifically working memory (Reynolds & Voress, 2007). An alternative was to develop and use working memory tests specific for the research (Stone & Towse, 2015). The tests would have to be tested on a small group of students to ensure that they had the correct level of demand and discriminated to the required level. An advantage of this was that a set of tests could be developed for the research which was easy and efficient for teachers to administer in a classroom setting. This would mean that a larger number of students could be used in the research study. Furthermore, the large number of students being used in the study would mean that the data could be statistically standardised to establish the mean of a normal distribution. However, developing working memory tests that have never been used in a research study before might compromise the validity and rigour of the data collected. This could leave the conclusions of the study open to criticism from peer reviews.

Table 38 The different commercial packages available to test WM of KS3 students

WM test	Cost	Disadvantages	Advantages	Other relevant information
Automated Working Memory Assessment (Packiam Alloway, Automated Working Memory Assessment Manual, 2007)	No longer available, can be renewed until 01.12.2017 if you already have the product	Very time consuming to administer (10 mins per student) Requires a one to one with a trained administrator	Gives results for each aspect of WM hence has detail, rigour and validity. The tests are specific to WM	The King's School did have the licence and a trained administrator
Working Memory Rating Scale (Unknown, n.d.)	£55.54 (Unknown, n.d.)	Aimed at ages 7-11 years Possibly lacks rigour	Is very easy to administer hence not as time consuming	Not of any use as age norm scales used that would not apply to KS3 students
Working Memory Test Battery for Children (Unknown, n.d.)	Not Available any more (Unknown, n.d.)			
Weschler Intelligence Scale for Children (Packiam Alloway & Alloway, 2015)	£1275.83 (Unknown, n.d.)	The tests have a lot of verbal information so students who are weak with this will not score well and give a false negative (Packiam Alloway & Alloway, 2015) Extremely expensive	Able to use this test with students up to the age of 16 years	
Woodcock-Johnson Tests of Cognitive Abilities (WJ Cog) (Packiam Alloway & Alloway, 2015)	Unable to find a UK supplier	If students do not know their numbers or letters very well then, the results might give a false	Able to use this test with students up to the age of 16 years	

		negative (show the students has a poorer WM then they actually have (Packiam Alloway & Alloway, 2015)		
Cross battery testing: Using a selection of tests from two or three different batteries of tests (Dehn, 2008)	Varies *See Table Three*	Potential to be very expensive as using a combination of different intelligence test batteries. Some of the tests are extremely time consuming so this might not be possible within the constraints of the research	Would be able to generate reliable data. Data would discern between the different WM constructs of each student. Would be able to source tests which were age appropriate	

Working Memory Tests within intelligence testing batteries

Table 39 Intelligence Cognitive Tests with Memory Subtests that Could be Used In Cross Battery Working Memory Testing

Intelligence Cognitive Test Battery	Cost	Advantages	Disadvantages
Stanford-Binet Intelligence Scales Fifth Edition (Dehn, 2008)	£1000 +VAT	Has three WM tests that cover verbal, visuospatial and executive processing. Is age appropriate for KS3 students	Some of the tests would be hard to administer in large groups i.e., block span test (Dehn, 2008) Can only be administered by an Educational Psychologist

Differential Ability Scales Second Edition (Dehn, 2008)	Not available in UK well over $1000 from US	Test executive WM with digit and word recall tests. It is age appropriate and can identify exceptional performance in students. Provides test that are very good at testing the specific part of memory they are designed to test for without overlap to other constructs (Dehn, 2008)	The cost. The recall test includes digits. The forward digit recall allows time for rehearsal (Dehn, 2008)l. Can only be administered by an Educational Psychologist
Kaufman Assessment Battery for Children Second Edition (Dehn, 2008)	£461.43 inc VAT	Word Order Test assesses students for executive WM There are two tests that assess WM and LTM function (Dehn, 2008).	The cost. The tests would have to be completed individually with each student in the research project this is extremely time consuming (Dehn, 2008) Can only be administered by an Educational Psychologist
Cognitive Assessment System (Dehn, 2008)	£1038	WM tests (Verbal WM and Executive WM) Students with high CAS scores have high attainment, Age range up to 18 years (Dehn, 2008)	Critics of CAS state that its' tests are heavily biased towards STM (Dehn, 2008) Can only be administered by an Educational Psychologist
Woodcock Johnson III Tests of Cognitive Abilities	Cannot find a UK company that is selling this currently	WM tests that cover verbal, auditory, executive WM, Age range up to 90 years+ (Dehn, 2008)	Compuscore makes the analysis complex in order to get useful data when just using WM tests (Dehn, 2008) Can only be administered by an Educational Psychologist
Universal Nonverbal Intelligence Test	Cannot find a UK company that is selling this currently	All tests completely non-verbal (Dehn, 2008)	Does not test WM very well if at all (Dehn, 2008) Can only be administered by an Educational Psychologist

The Wechsler Scales	£1275.83 (Unknown, n.d.)	Tests verbal and executive WM (Dehn, 2008)	All three tests need to be used to be able to get the WM score (Dehn, 2008)
WISC-IV Integrated	£1275.83 (Unknown, n.d.)	Has one of the most comprehensive sets of tests for WM (Dehn, 2008) Able to use this test with students up to the age of 16 years (Dehn, 2008)	The tests have a lot of verbal information so students who are weak with this will not score well and give a false negative (Packiam Alloway & Alloway, 2015) Extremely expensive Difficult to gain scores specific to WM without complex analysis due to original set up and aim of tests (Dehn, 2008)
The NEPSY II: A Developmental Neuropsychological Assessment	£1309.80 (Unknown, n.d.)	Aimed at ages 3-16 years Tests verbal and executive WM (Dehn, 2008)	The tests are difficult to run logistically and difficult to record the scores of the students (Dehn, 2008) Can only be administered by an Educational Psychologist
TOMAL 2	£464.40 plus additional costs £532.80 for test and profile booklets) (Unknown, n.d.)	Aimed at 5-59 years Comprehensive assessment of non-verbal and verbal memory Test takes 30 mins (Reynolds & Voress, 2007)	Would have to be administered on a one-to-one basis. (Reynolds & Voress, 2007) Would have significant costs
Lucid Recall (St. Clair-Thompson, 2015)	Prices vary depending on options £90.95 - £1560.95	Aimed at 7-16 years Tests Phonological Loop (Verbal WM), The Central Executive, Visual Spatial Standardised Scores	Would have to be administered to students in an IT suite (10 at a time to be economic)

		Takes 30-40 minutes	

Using the WM tests off the shelf or WM batteries of tests within Intelligence tests was not possible due to the time taken to administer these tasks and the huge cost implication. Furthermore, it would be extremely time consuming to design Working Memory tests specifically for this research and this might also compromise the validity of the results and hence conclusions drawn from the research. This leaves the possibility of using open ware software or other tests that researchers have published for other researchers to use.

Working Memory Test Batteries Available from Open Research

Table 40 outlines the advantages and disadvantages of the open ware software WM tests available. Beneath Table four is a more detailed discussion of the benefits and drawbacks of the open ware.

Table 40 The available open ware alongside the advantages and disadvantages of each software package

Name or Source of Openware	Website open ware is available from	Advantages	Disadvantages
Cognitive Tools: WM Test Battery	http://www.cognitivetools.uk	Easy to administer tests Data easy to export on csv file	Scores are not standardised
Matlab: WM tests	www.cogsciwa.com	Excellent WM tests	Expensive licence fee making this option prohibitive Scores are not standardised

The Psychology Experiment Building Language: WM tests	http://pebl.sourceforge.net	5 WM tests Downloadable Flexibility to re-write tests via re-coding	The software is not compatible with all computers so might not run-in school IT suites.
Georgia Institute of Technology: five WM tests	http://psychologygatech.edu/renglelab http://englelab.gatech.edu	Software will run on many computers using E-prime software. The tests can be designed to suit the individual purposed of the research or a WM battery of tests can be downloaded and used. Short versions of these tests have been verified as being as rigorous	The WM test battery might not be comprehensive enough for the measure of WM required for this research. The original tests take a long time to administer (Foster, et al., 2015) Scores are not standardised

		as the longer version (Foster, et al., 2015) These tests are reliable and valid	
WoMMBAT (Working Memory Battery of Tests) Nine tests	Currently trying to find out how to access this resource.	Able to discriminate between how good static and dynamic visual spatial WM using tests (Englund, et al., 2014) Available online for students to take on computers either at home or at school Only takes 30-50 minutes so could be done in an hour lesson	The tests do not give a measure of WM executive function. Furthermore, the initial testing showed that a some of the tests did not contribute to the WM score and hence this brings into question the reliability of the test scores (Englund, et al., 2014) Scores not standardised.

		(Englund, et al., 2014) Would give separate scores for Verbal, Static Visual Spatial and Dynamic Visual Spatial WM (Englund, et al., 2014)	

There are a number of WM test batteries that have been published as freeware or free software by researchers. If this research was to use change detection tests the data could be analysed using open access software WOMMBAT (Morey & Morey, 2011).

A battery of nine tests has been developed to assess WM. This set of nine tests is called WOMBAT (Working Memory Battery). The WOMBAT tests are able to make a distinction between static visual spatial working memory and dynamic visual spatial working memory. This could be important when assessing the link between academic attainment and WM (Englund, et al., 2014) . WOMBAT was designed to be administered by teachers with students in schools with two specific aims. To identify students who have weak WM so intervention can be used to support these students in their learning. In addition to establish a WM profile of students to enable teachers to inform their planning accordingly. It has the ability to give separate scores for three different aspects of WM. These three aspects are Verbal WM, Static Visual Spatial WM and Dynamic Visual Spatial WM (Englund, et al., 2014). The tests do not give a measure of WM executive function. Furthermore, the initial testing showed that a some of the tests did not contribute to the WM score and hence this brings into question the reliability of the test scores (Englund, et al., 2014). However, the authors think after refinement the tests would be suitable for use and even state that they could be used for pp. 5 “pre and postintervention” scores in schools (Englund, et al., 2014).

Researchers have used Matlab and the free Psychophysics Toolbox to publish a set of WM tests that have been designed to be used on computers. These test a range of aspects of WM and hence will give a good overall rating of an individual’s WM (Stone & Towse, 2015; Lewandowsky, et al., 2010). However, although the tests are freely available, they need software from Matlab. An academic license for each computer at school would have been costly to the point of stopping the use of this product for this research project. This is disappointing as the Matlab tests can be re-coded to tailor the tests to the specific research project. The Psychology Experiment Building Language (PEBL) (Mueller & Piper, 2014)also gave me the opportunity to write my own tests to run on the software. However, the PEBL when downloaded does come with a set of five tests that can be used to measure WM. The PEBL tests were free to download to as many computers as needed for the research. This would have been real advantage because license fees for a large number of computers in one or more schools would have meant that this was an option which was too expensive (Mueller & Piper, 2014).

Alternatively, if the PEBL WM tests were not able to run on the school computers as needed there is an alternative of the cognitive tools project. The cognitive tools project has published open ware software in the form of seven different tests that use the Tatool platform. When these seven tests are taken collectively, they give a good measure of a student’s WM. These tests are available at http://www.cognitivetools.uk together with the source code to modify the tests and ability to deliver the tests as a randomised battery. (Stone J. , 2015). .

Aospan is a set of WM tests that can be administered simply as there is no need for me to interact with the software once the student is taking the tests. All the tests can be conducted just using a computer mouse (Unsworth, et al., 2005) E-prime software as opposed to the Tatool platform that has been used to develop and make available five tests that are able to test WM.

These tests have been also been modified so there are versions that have a quicker completion time. This would have been an advantage with this WM research project (Stone & Towse, 2015). Versions of the Aospan tests have been developed that are much shorted but are still able assess WM effectively (Foster, et al., 2015). This would be a huge advantage in a longitudinal study such as this with a large number of students to assess.

The availability of freeware and free software WM test batteries means that each student could take a number of tests. Hence the results will better represent the WM of each student. Furthermore, each student taking a battery of tests reduces the task-specific variance one would expect to see if students were just doing one complex- span memory test (Lewandowsky, et al., 2010). However, none of the free software has standardised tests.

Appendix C: Data Analysis of Quantitative Data

Introduction to Appendix C

Appendix C contains data analysis tables. The first part has a series of tables that have the outcomes of correlations between WM baseline tests and Science attainment scores. The second part had dependent paired t-test results of the control group pre and post science attainment scores and active group pre and post science attainment scores in Year 7 & 8. Finally, the third part has Year 8 Independent T-test results from comparing the control to the active groups' science attainment results.

Quantitative Tables of Data Baseline WM tests with Science attainment correlations for Comparison & Reference

Table 41 Baseline WM Test correlation to Year 8 Science Investigation Attainment Grades

Control Group			**Active Group**		
		P Value			**P Value**
Word Recall	Pendulum Obtaining Evidence	0.004	Word Recall	Pendulum Obtaining Evidence	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		0.015	Counting Recall		Not significant
Working Memory Composite		0.004	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall		Not significant	Word Recall		Not significant

Pattern Recall	Pendulum Analysis	Not significant	Pattern Recall	Pendulum Analysis	Not significant
Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall		Not significant	Word Recall		Not significant
Pattern Recall	Reactivity Series Planning	Not significant	Pattern Recall	Reactivity Series Planning	Not significant
Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall		Not significant	Word Recall		Not significant
Pattern Recall	Reactivity Series Evaluation	0.05	Pattern Recall	Reactivity Series Evaluation	Not significant
Counting Recall		Not significant	Counting Recall		
Working Memory Composite		Not significant	Working Memory Composite		

Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall	Seed dispersal Obtaining Evidence	Not significant	Word Recall	Seed dispersal Obtaining Evidence	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		Not significant	Counting Recall		0.031
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		0.023	Working Memory Processing		Not significant
Word Recall	Seed dispersal Analysis	Not significant	Word Recall	Seed dispersal Analysis	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		0.028	Working Memory Processing		Not significant
Word Recall	Sound Planning	Not significant	Word Recall	Sound Planning	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant

Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall	Sound Analysis	Not significant	Word Recall	Sound Analysis	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		Not significant	Counting Recall		0.026
Working Memory Composite		Not significant	Working Memory Composite		0.036
Working Memory Processing		Not significant	Working Memory Processing		Not significant

Table 42 Baseline WM test correlation to Year 8 Science Attainment Grades (for comparison)

Control Group			**Active Group**		
		P Value			**P Value**
Word Recall	Year 8 Test 1	0.002	Word Recall	Year 8 Test 1	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant

Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall	Year 8 Test 2	0.0017	Word Recall	Year 8 Test 2	Not significant
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		Not significant	Counting Recall		Not significant
Working Memory Composite		Not significant	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant
Word Recall	End of Y8 Report	0.000 (signif to 0.01)	Word Recall	End of Y8 Report	0.04
Pattern Recall		Not significant	Pattern Recall		Not significant
Counting Recall		0.003	Counting Recall		Not significant
Working Memory Composite		0.000	Working Memory Composite		Not significant
Working Memory Processing		Not significant	Working Memory Processing		Not significant

Dependent Paired t test data tables for the control group Science attainment results and the active groups Science attainment results to allow for comparisons between the control and active groups.

Link below is where I sourced the critical values for the statistical analysis of t-tests t Critical Value Calculator - The Free Statistics Site (statscalculator.com)

Table 43 The Control Group Students paired t-test results of Year 7 Test 1 means Compared to the Year 8 Science Attainment and End of Year 7 Grade Compared to Year 8 Science Attainment

Control Paired t- Test Results						
Variable 1	Variable 2	Lower	Upper	t value	CV	P value
Y7 Test 1	Y8Test 1	-0.24729	-0.18322	-13.45155	2.00	0.000
Y7 Test 1	Y8Test 2	-0.21509	-0.13745	-9.090	2.00	0.000
Y7 Test 1	End of Y8 Grade	-0.21509	-0.13745	-9.090	2.00	0.000
End of Y7 Grade	Y8 Test 1	-0.20147	-0.14297	-11.700	1.99	0.000
End of Y7 Grade	Y8Test 2	-0.17906	-0.11427	-8.996	1.99	0.000
End of Y7 Grade	End of Y8 Grade	-0.17589	-0.12748	-12.452	1.99	0.000

Table 44 The Active Group Students paired t-test results of Year 7 Test 1 means Compared to the Year 8 Science Attainment and End of Year 7 Grade Compared to Year 8 Science Attainment

Active Paired t- Test Results						
Variable 1	Variable 2	Lower	Upper	t value	CV	P value
Y7 Test 1	Y8Test 1	-0.26161	-0.19518	-13.686	1.99	0.000
Y7 Test 1	Y8Test 2	-0.27559	-0.21191	-15.239	1.99	0.000
Y7 Test 1	End of Y8 Grade	-0.23684	-0.17864	-14.198	1.99	0.000

End of Y7 Grade	Y8 Test 1	-0.22028	-0.14790	-10.111	1.99	0.000
End of Y7 Grade	Y8Test 2	-0.23833	-0.16288	-10.578	1.99	0.000
End of Y7 Grade	End of Y8 Grade	-0.19338	-0.12821	-9.809	1.99	0.000

Table 45 The results of the paired t-tests for the Control students, comparing the means of baseline investigative skills with the means of the Year 8 investigative skills assessment

Control Paired t-test Results						
Variable 1	Variable 2	Lower	Upper	t value	CV	P value
Baseline planning grade	Y8 Reaction Series Planning	-0.16518	-0.07926	-5.848	2.06	0.000
Baseline Obtaining Evidence	Y8 Pendulum Obtaining Evidence	-0.27514	-0.14409	-6.422	2.01	0.000
Baseline Analysis	Y8 Pendulum Analysis	-0.15477	-0.03189	-3.040	2.00	0.004
Baseline Evaluating	Y8 Reaction Series Evaluation	-0.37676	-0.08991	-7.000	4.30	0.020
Baseline Obtaining Evidence	Seed Dispersal Obtaining Evidence	-0.31843	-0.21014	-9.781	2.00	0.000

Baseline Analysis	Seed Dispersal Analysis	-0.21155	-0.13778	-9.436	1.99	0.000

Table 46 The results of the paired t-tests for the Active students, comparing the means of baseline investigative skills with the means of the Year 8 investigative skills assessment

Active Students paired t-Test Results						
Variable 1	Variable 2	Lower	Upper	t value	CV	P value
Baseline planning grade	Y8 Reaction Series Planning	-0.21096	-0.10504	-5.995	2.01	0.000
Baseline Obtaining Evidence	Y8 Pendulum Obtaining Evidence	-0.32316	-0.22478	-11.103	1.99	0.000
Baseline Analysis	Y8 Pendulum Analysis	-0.14608	-0.05932	-4.718	1.99	0.000
Baseline Evaluating	Y8 Reaction Series Evaluation	-0.15841	-0.00288	-2.118	2.04	0.043
Baseline Obtaining Evidence	Seed Dispersal Obtaining Evidence	-0.22088	-0.12806	-7.567	2.01	0.000
Baseline Analysis	Seed Dispersal Analysis	-0.09406	-0.00390	-2.184	2.01	0.034
Baseline planning	Y8 Sound Planning	-0.12695	-0.02505	-3.079	2.06	0.005
Baseline analysis	Y8 Sound analysis	-0.19095	-0.10560	-7.117	2.05	0.000

Year 8 Independent t tests Comparing Control Group Science attainment results to Active Group Science attainment results

Table 47 Independent t-test outcomes for Science attainment in Year 8

Comparing Con to Act					
Variable	Lower	Upper	t value	CV	P value
Y8Test 1	-0.0486	0.0313	-0.426	1.97	0.671
Y8Test 2	-0.0821	-0.0122	-2.660	1.97	0.009
End of Y8 Grade	- 0.03554	0.03702	0.040	1.97	0.968
Pendlm:Obtaining	-0.1514	-0.0554	-4.256	1.97	0.000
Pendlm:Analysis	-0.1361	-0.0115	-2.343	1.98	0.021
ReactSer:Planning	-0.1137	0.0161	-1.495	1.99	0.139
ReactSer:Evaluating	-0.305	-0.1083	0.0798	2.01	0.761
SeedDisp:Obtaining	-0.0140	0.0852	1.419	1.98	0.158
SeedDisp:Analysis	- 0.03554	0.03702	0.040	1.97	0.968

Appendix D: Data Analysis: Student Perception Data From Year 7 & Year 8 Student Questionnaires

Introduction to Appendix D

Appendix D contains the analysis of student perception data from Year 7 and Year 8 student questionnaires. The first section contains the analysis tables comparing the control and active group responses for Year 7 and Year 8 student questionnaires. The second and third section contain tables that show the analysis of the control and active group Year 7 responses to the student questionnaire. The fourth and fifth sections contain comparisons between the active group and control group of the responses to the student questionnaire; the start of the study and the end of the study respectively. Finally, the sixth section has the analysis of the written comments that were written on the student questionnaire.

Year 7 & 8 Student Questionnaire Analysis Tables

Table 48 The difference between the control and the active group responses for each questionnaire.

Qs	Qre 1 compared to Qre 1 Difference between the control and active responses %			Qre 2 compared to Qre 2 Difference between the control and active responses %			Qre 3 compared to Qre 3 Difference between the control and active responses %			Qre 4 compared to Qre 4 Difference between the control and active responses %		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	6.8	-0.1	-6.7	15.1	-12	-3						
I think that having a good memory is important for learning	0.8	-2	1.2	8.6	-7.5	-1.2						
I think having a good memory is part of being intelligent	-20.6	18	1.4	-1.2	32.4	-34.6						
In science lessons I do activities to	42.1	-27.5	-14.6	39.4	-23.5	-15.9						

practice using my memory												
In other subjects I do activities to practice using my memory	-6	6.7	-0.8	-10.8	13.9	-1.9						
I use the memory skills I practice in Science in other subjects	-4.8	8.7	-6.3	-3.7	7.9	-3						
I am learning new information and skills in Science	16.7	-16.7	1.2	8.3	-5.9	-2.4						
I have a good memory	-3.5	7.4	-5.2	-12.4	11.9	0.4						
I am intelligent	-1.1	2.9	-3	-0.8	11.7	-11						

Key
A large difference indicating WM activities may have a positive impact
A large difference suggesting WM activities may not be having a positive impact
Questions that have require students to think metacognitively
An interesting observation of other memory input experience by students in the research study

Table 48 shows the difference in responses between the control and the active group in percentage between the first questionnaire and the subsequent three questionnaires in the study,

SEE Document in Qual Data (Data Analysis folder) Y7_&Y8 LessObs Qre raw data tables

Analysis of the Year 7 control group student questionnaire responses

A comparison between the control group responses from the first and second student questionnaire is show in Table 49. Overall, there are more decreases in responses from the start of the study to the end of year 7 with the exception of "***In science lessons I do activities to practice using my memory"***, "***I am learning new information and skills in Science"***, "***I have a good memory"*** and ***"I am intelligent"***.

Table 49 A comparison between the control group responses from the first and second student questionnaire

	Control Questionnaire 1 %			Control Questionnaire 2 %			Difference %		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	26.1	64.8	9.1	23.5	70.6	5.9	-2.6	5.8	-3.2
I think that having a good memory is important for learning	89.8	10.2	0.0	87.1	11.8	1.2	-2.7	1.6	1.2
I think having a good memory is part of being intelligent	50.0	42.0	8.0	35.3	15.3	49.4	-14.7	-26.7	41.4
In science **lessons I do activities to practice using my** memory	26.1	53.4	20.5	30.6	50.6	18.8	4.5	-2.8	-1.7
In other subjects I do activities to practice using my memory	30.7	58.0	11.4	29.4	51.8	17.6	-1.3	-6.2	6.2
I use the memory skills I practice in Science in	33.0	46.6	20.5	29.4	43.5	25.9	-3.6	-3.1	5.4

other subjects									
I am learning new information and skills in Science	72.7	26.1	0.0	78.8	18.8	2.4	6.1	-7.3	2.4
I have a good memory	34.1	45.5	20.5	42.4	42.4	15.3	8.3	-3.1	-5.2
I am intelligent	36.4	47.7	15.9	36.5	41.2	22.4	0.1	-6.5	6.5

Key
An increase in positive response
A decrease in positive response
Questions that have require students to think metacognitively

Analysis of the Year 7 active group student questionnaire responses

A comparison between the active group responses from the first and second student questionnaire is show in Table 50. Overall, there are more increases in responses from the start of the study to the end of year 7 with the exception of decreases in; "***In other subjects I do activities to practice using my memory"," I use the memory skills I practice in Science in other subjects"," I am learning new information and skills in Science"*** and ***" I have a good memory".*** Furthermore, the active group responses become more emphatic and decisive for ***"I think having a good memory is part of being intelligent"*** with the; "a bit" response declining, where as the "yes" and "no" responses went up by equal measure. This could be attributed to an increase in metacognition regarding this question.

Table 50 A comparison between the active group responses from the first and second student questionnaire

	Active Questionnaire 1			Active Questionnaire 2			Difference		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	32.9	64.7	2.4	38.6	58.6	2.9	5.7	-6.1	0.5
I think that having a good memory is important for learning	90.6	8.2	1.2	95.7	4.3	0	5.1	-3.9	-1.2
I think having a good memory is part of being intelligent	29.4	60	9.4	34.1	47.7	14.8	4.7	-12.3	5.4
In science **lessons I do activities to practice using my** memory	68.2	25.9	5.9	70	27.1	2.9	1.8	1.2	-3
In other subjects I do activities to practice using my memory	24.7	64.7	10.6	18.6	65.7	15.7	-6.1	1	5.1
I use the memory skills I practice in Science in other subjects	28.2	55.3	14.2	25.7	51.4	22.9	-2.5	-3.9	8.7

I am learning new information and skills in Science	89.4	9.4	1.2	87.1	12.9	0	-2.3	3.5	-1.2
I have a good memory	30.6	52.9	15.3	30	54.3	15.7	-0.6	1.4	0.4
I am intelligent	35.3	50.6	12.9	35.7	52.9	11.4	0.4	2.3	-1.5

Key
An increase in positive response
A decrease in positive response
Questions that have require students to think metacognitively

Overall, the control group have become more negative about memory and learning. Whereas the active group have become more positive about memory and learning. On the other hand, the active group have a slightly more negative perception of their own memory at the end of the year 7. The active group also have a slight decline on students thinking they learn new information and skills. Furthermore, the control group has an increase in students stating ***"In science lessons I do activities to practice using my memory"***. This is likely to be due to the use of reading sheets in the control group lessons.

Analysis of the comparison between the active and control group beginning of the study questionnaire

Table 51 shows a comparison of the responses between the control group and active group for the first questionnaire. The comparison between the control group and active group first student questionnaire responses show, that during the earlier stage of the study fewer active group students thought that having a good memory was important for intelligence. Unsurprisingly, there is a large difference between the number of students stating yes to the statement; ***"In science lessons I do activities to practice using my memory"***. There were a larger number of active group students responding positively to ***"I can remember information from lessons really well".*** However, the active group students were more negative than the control group about their perception of their own memory and intelligence.

Furthermore, during the early stages of the study fewer students in the active group stated yes to ***"I use the memory skills I practice in Science in other subjects"*** but more active group students stated a bit in response to the statement compared to the control group. On the other hand, compared to the control group a great deal more active group students stated yes to the statement ***"I am learning new information and skills in Science"***.

So overall, when comparing the responses of the control group to the active group to the first student questionnaire. The active group have the largest positive responses to ***"In science lessons I do activities to practice using my memory"*** and ***"I am learning new information and skills in Science"*** but on the other hand the active group were more negative when responding to ***"I think having a good memory is part of being intelligent".*** A tentative conclusion indicated by this qualitative data would be that during the early stages of the study the active group (compared to the control) are experiencing the activities to develop working memory, that is contributing to their positive perception of their learning in science. Despite this conclusion, in the early stages of the study metacognitively the control group see a positive connection between memory and learning that the active group do not.

Table 51 The comparison between the responses of first questionnaire for the control and active group

	Control Questionnaire 1 Responses %			Active Questionnaire 1 Responses %			Difference between the control and active responses %		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	26.1	64.8	9.1	32.9	64.7	2.4	6.8	-0.1	-6.7
I think that having a good memory is important for learning	89.8	10.2	0	90.6	8.2	1.2	0.8	-2	1.2
I think having a good memory is part of being intelligent	50	42	8	29.4	60	9.4	-20.6	18	1.4
In science **lessons I do activities to practice**	26.1	53.4	20.5	68.2	25.9	5.9	42.1	-27.5	-14.6

using my memory									
In other subjects I do activities to practice using my memory	30.7	58	11.4	24.7	64.7	10.6	-6	6.7	-0.8
I use the memory skills I practice in Science in other subjects	33	46.6	20.5	28.2	55.3	14.2	-4.8	8.7	-6.3
I am learning new information and skills in Science	72.7	26.1	0	89.4	9.4	1.2	16.7	-16.7	1.2
I have a good memory	34.1	45.5	20.5	30.6	52.9	15.3	-3.5	7.4	-5.2
I am intelligent	36.4	47.7	15.9	35.3	50.6	12.9	-1.1	2.9	-3

Key
A large difference for Working Memory having an impact
A large difference against Working Memory having an impact
Questions that have require students to think metacognitively
An interesting observation of other memory input experience by students in the research study

Analysis of the comparison between the active and control group end of Year 7 questionnaire

Table 52 shows a comparison of the responses between the control group and active group for the second questionnaire.

The comparison between the control group and active group second student questionnaire responses shows that during the latter stages of Year 7; a larger percentage of the active group compared to the control group have responded “yes” to ***“I can remember information from lessons really well”*** , ***“I think that having a good memory is important for learning”, “In science lessons I do activities to practice using my memory”*** and ***“I am learning new information and skills in Science”.*** When difference between the control and active groups “a bit” and “no” responses are considered for these responses, they show a decrease in the percentage for the active group. This supports the positive increase shown.

The active group have responded more positively using the “yes” response to statements, compared to the control group. The control group have used the response “no” more than the active group. As the statements are all worded to be linked to learning, memory, memory activities then these differences in the way the active and the control group respond indicate that the Working Memory activities may be having a positive impact on the students’ perception of their learning and memory.

On the other hand, a larger percentage of the control group compared to the active group have responded “yes” to ***“I use the memory skills I practice in Science in other lessons”*** and ***“I have a good memory”.*** However, Tables 49 and 50 (p. 415 & 417) show both the control group and the active group showing a similar percentage decline in the “yes” response to ***“I use the memory skills I practice in Science in other lessons”*** from the beginning of the study to the end of the year 7 of the study. The larger percentage of the control group responding “yes” and the decline in the active group’s response from the beginning of the study indicates that the working memory activities may not having a far transfer effect to other subjects. Although in Table 49 the control group have an increase in the "yes" response. Table 50 shows a small 0.6% decline in students responding "yes" for the beginning of the study to the end of year 7 in the active group. So, the working memory activities may not be making the active group students feel positive about their memory, but the data does not show a negative impact either.

A larger percentage of the active group have responded "a bit", compared to the control group for the following statements; ***"I think having a good memory is part of being intelligent", "I use the memory skills I practice in Science in other subjects", "I have a good memory"*** and ***"I am intelligent".***

The larger "a bit" response to the statement ***"I think having a good memory is part of being intelligent"*** from the active group is further supported by the large negative difference in the response "no" to the same statement. Table 52 shows that the decrease is 34.6 % in the "no" response, whereas the increase in the "a bit" response was 32.4%. Hence, further supporting the difference in the active group compared to the control group for this statement.

The larger "a bit" response for the active group to the statement ***"I use the memory skills I practice in Science in other subjects"*** alongside the smaller "no" response leads to a slightly different conclusion to earlier. The response to this statement is important because having evidence that may support the far transfer effects of working memory activities is very rare in education research. When the "yes" and "a bit" responses are added together the totals are 72.9% of the control group students compared to 77.1% of the active group. This shows a slightly higher percentage in the active group. This could very tentatively indicate that the working memory activities are having far transfer effects.

The active groups' larger response of a "a bit" to ***"I have a good memory"*** and ***"I am intelligent"*** to the statements indicates that they do have a somewhat positive perception of their own memory and intelligence. This is supported further, for the "***I have a good memory".*** The percentage of students in the control group, and the active group for the "no" response being about the same (15.3% and 15.7% respectively) ; indicating that a similar percentage of students were positive about their memory. However, quantitative data does support the conclusion that the control students are more emphatically positive about their memory. The responses to the ***"I am intelligent"*** support a different conclusion. There are a larger percentage of the active group students that responded "a bit" to the statement. If you look at all the response data; there is very little difference between the control and the active group for the "yes" response (36.5% and 35.7% respectively). But, a much larger percentage of control group students responded "no", compared to the active group (22.4% and 11.4% respectively). The active group have a larger percentage 88.8% of students responding positively to the intelligent statement compared to the control groups' percentage of 77.7%. This leads to the tentative conclusion that after the first year of the study working memory activities do not have and any discernible impact on students' perception of their memory. On the other hand, this quantitative data supports the tentative conclusion that after the first year of the study working memory activities are having a positive impact on how students perceive their own intelligence.

Table 52 The comparison between the responses of second questionnaire for the control and active group

	Control Questionnaire 2 Responses %			Active Questionnaire 2 Responses %			Difference between the control and active responses %		
	Yes	A Bit	No	Yes	A Bit	No	Yes	A Bit	No
I can remember information from lessons really well	23.5	70.6	5.9	38.6	58.6	2.9	15.1	-12	-3
I think that having a good memory is important for learning	87.1	11.8	1.2	95.7	4.3	0	8.6	-7.5	-1.2
I think having a good memory is part of being intelligent	35.3	15.3	49.4	34.1	47.7	14.8	-1.2	32.4	-34.6
In science **lessons I do activities to practice using my** memory	30.6	50.6	18.8	70	27.1	2.9	39.4	-23.5	-15.9
In other subjects I do activities to practice using my memory	29.4	51.8	17.6	18.6	65.7	15.7	-10.8	13.9	-1.9

I use the memory skills I practice in Science in other subjects	29.4	43.5	25.9	25.7	51.4	22.9	-3.7	7.9	-3
I am learning new information and skills in Science	78.8	18.8	2.4	87.1	12.9	0	8.3	-5.9	-2.4
I have a good memory	42.4	42.4	15.3	30	54.3	15.7	-12.4	11.9	0.4
I am intelligent	36.5	41.2	22.4	35.7	52.9	11.4	-0.8	11.7	-11

Key
A large difference for Working Memory having an impact
A large difference against Working Memory having an impact
Questions that have require students to think metacognitively
An interesting observation of other memory input experience by students in the research study

Analysis of the comments written on the student questionnaire

Table 53 The comments written by control and active group students at the beginning of the study and the end of year 7 student questionnaire

Questionnaire 1 Comments		**Questionnaire 2 Comments**	
Control Group	Active Group	Control Group	Active Group
I don't want to seem big headed. But I feel that I'm intelligent also I've got a terrible memory, but I am good at lots of subjects but I usually have to learn things 3 or 4 times to get it in my head.	Left last one blank stating "I would rather not answer the last Q."	I put the middle for the last one ("***I am intelligent***") as yes in some subjects but in others I'm a bit out of my comfort zone. And I find them a bit boring as I'm not happy as I find them a bit boring and then I won't work as hard.	I feel I have improved
I think we should watch more videos	I think we should do this in every lesson	I remember better if we have a little quiz on it or something like that	
I remember things better if someone says it to me	I'm partially dyslexic I can't always remember things	Has ticked the no box for last Q("***I am intelligent***") three times	

you need to have a good memory otherwise you don't learn; learning is remembering		We need more science lessons!	
I find it hard to remember information in science		Science teacher 4 is amazing!	
I can remember quite a bit of things but not everything from a lesson		I am not really sure if I am intelligent	
I find stuff difficult		Having a good memory help being intelligent but if you don't have a good memory, it doesn't stop you being intelligent	
Sometimes I can't remember what the task is I think a bit of it is my dyslexic tendencies			
"***I am intelligent***" student commented: " it depends on the subject"			

Table 53 shows the all the comments (and significant observations) from the student questionnaires. The control group students have written more comments (had more significant observations) compared to the active group. The control group comments (and significant observations) from the questionnaire at the start of the study show 3 positive responses (that were positive about themselves, learning, memory, science or showed metacognition), 3 neutral responses, and 3 negative responses (that were negative about themselves, learning, memory, science or showed metacognition). . The active group comments (and significant observations) from the questionnaire at the start of the study show 1 positive responses (that were positive about themselves, learning, memory, science or showed metacognition), zero neutral responses, and 1 negative responses (that were negative about themselves, learning, memory, science or showed metacognition).

The control group comments (and significant observations) from the questionnaire at the end of Year 7 shows 5 positive responses (that were positive about themselves, learning, memory, science or showed metacognition), 1 neutral responses, and 1 negative responses (that were negative about themselves, learning, memory, science or showed metacognition). The active group comment (and significant observations) from the questionnaire at the end of Year 7 show 1 positive responses (that were positive about themselves, learning, memory, science or showed metacognition).

Overall, the control group students wanted to comment more on the study than the active group students. The students wanted to comment less at the end of Year 7 compared to the beginning of the study. The students in both the control and the active group were more positive in their responses (about themselves, learning, memory, science or showed metacognition) at the end of the Year 7 compared to the beginning of the study.

Appendix E: Data Analysis of Qualitative Data Year 7 and Year 8 Student Interview Responses

Introduction to Appendix E

Appendix E contains qualitative data analysis tables from the Year 7 and 8 student interview responses. The first section contains tables of data analysis for the student interview responses conducted in Year 7 and the second section contains the tables of data analysis for the student interview responses in Year 8.

Year 7 Student Interview Responses Raw Data Tables

Table 54 The Year 7 student quantifiable responses to interviews that took place in the lesson observations

Question	Response	Percentage of Responses %	
		Control	Active
Do you do memory activities in your lessons?	Yes	0	100
	No	100	0
(If Yes) Do you find memory activities useful for your learning?	A lot		28
	Yes		64
	A bit		2
	No		4
Do you find Science easy, medium or difficult?	Easy	18	4
	Medium	82	84
	Difficult	0	8
	No Response	0	4
What activities do you do in Science that help	Practical work	44	38
	Reading Sheets	8	12

you learn the most? (first activity students stated)	WM listening activities	0	12
	All Activities	0	8
	Quiz	0	6
	Other*	50	24
*Other	All had 4% each	Dissections Flashcards Quiz Read Notes Worksheets	Demos Written work
	All had 2% each	Active Learning Burning Stuff Chemistry Diagrams Making Posters PowerPoints Research Revision Written Work	Being Creative Dissections Life Examples Flash Cards Student Models Worksheets
What activities do you do in Science that help you learn the most? (second activity students stated)	Practical work	10	No students in the active group stated a second activity
	4%	videos	
	All had 2% each	Active Learning Cut and Stick Teacher Demos Explaining the Science Quiz	

Table 55 The frequency of responses to the question "Why do you find science easy/ medium/ difficult"

Response to question ***"Why do you find science easy/medium/difficult?"***	Control Group Frequency of response	Active Group Frequency of response
It is easy	3	1
Sometimes Science is easy and sometimes science is hard	20	10
STUDENTS FIND SCIENCE CHALLENGING	8	6
Student has stated that a specific area of science is more difficult than another	3	5
Science is a challenge but …(students justify its importance to them personally)	0	2
The teacher explains the science well	2	1
(……but) Fun	4	0
No comment	7	18

Table 56 The more specific responses of the students in the active and control group to the question "Why do you find science easy/ medium/ difficult"

Control group	Active group

Sometimes I don’t understand	Doesn’t take in information when the teacher explains it
Easier if you’re interested in the topic (some topics are boring)	Can be complicated; if the science is shown visually, I find it easier to understand
Sometimes the words are similar	There is a lot to remember and I struggle a bit
I am dyspraxic and dyslexic	Medium when I try really hard
I just love Science, I understand	It is because we use hard and easy ways to learn
Difficult words	The teacher sometimes doesn’t tell us what the symbols mean
Hard to remember everything	
For some(topics) I have to think deeply	
(Easy) Words get stuck in your head	

Year 8 Student Interview Responses and Raw Data Tables

Table 57 Active students' response to what activity in science helps them learn the most (first answer)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		4	8.5	8.5	8.5
	Activity	1	2.1	2.1	10.6
	Asking the teacher challenging questions	2	4.3	4.3	14.9
	Demonstrations	5	10.6	10.6	25.5
	Different book and pages given for independent revision	1	2.1	2.1	27.7
	Explanations on the board	1	2.1	2.1	29.8
	Graphs	1	2.1	2.1	31.9
	Labelling diagrams	1	2.1	2.1	34.0
	Listening Activities	4	10.6	10.6	44.7
	Listening to teacher explanations	2	4.3	4.3	48.9
	Practicals	14	29.8	29.8	78.7
					80.9
	Reading Sheets	4	10.6	10.6	89.4
	Reading through	1	2.1	2.1	91.5
	Research in the internet	1	2.1	2.1	93.6
	Worksheets	1	2.1	2.1	95.7
	Writing down from my head	1	2.1	2.1	97.9
	Writing down from the board	1	2.1	2.1	100.0

Table 58 Y8 Active students' response to what activity in science helps them learn the most (second answer)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		34	72.3	72.3	72.3
	Demonstrations	2	4.3	4.3	76.6
	Explanations on the board	1	2.1	2.1	78.7
	Practicals	2	4.3	4.3	83.0
	Reading Sheets	4	8.5	8.5	91.5
	The teacher helping with the writing	1	2.1	2.1	93.6
	Worksheets	2	4.3	4.3	97.9
	Writing down	1	2.1	2.1	100.0

Table 59 The Y8 Control student's response to what activity in science helps them learn the most (first answer)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		2	5.4	5.4	5.4
	Demonstrations	1	2.7	2.7	8.1
	Mnemonics	1	2.7	2.7	10.8
	Practicals	19	51.4	51.4	62.2
	Reading sheets	6	16.2	16.2	78.4
	Thinking about Science	1	2.7	2.7	81.1
	Video clips	2	5.4	5.4	86.5
	Worksheets	1	2.7	2.7	89.2
	Writes most important facts down on post it notes	1	2.7	2.7	91.9
	Writing down from the board	1	2.7	2.7	94.6
	Writing things down	2	5.4	5.4	100.0
	Total	37	100.0	100.0	

Table 60 The Y8 Control group students' response to what activity in science helps them learn the most (second answer)

CONSciLearn2nd

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		25	67.6	67.6	67.6
	Asking Questions	1	2.7	2.7	70.3
	Demonstrations	2	5.4	5.4	75.7
	Graphs	1	2.7	2.7	78.4
	Practicals	4	10.8	10.8	89.2
	Reading Sheets	1	2.7	2.7	91.9
	Sentence starters	1	2.7	2.7	94.6
	Teacher explanations	1	2.7	2.7	97.3
	Worksheets	1	2.7	2.7	100.0
	Total	37	100.0	100.0	

Table 61 The Analysis of students response in % to what activity in science helps them learn the most (first answer)

Question	Response	Percentage of Responses %	
		Control	Active
Do you do memory activities in your lessons?	Yes	0	100
	No	100	0
(If Yes) Do you find memory activities useful for your learning?	A lot	[redacted]	0
	Yes	[redacted]	83.0
	A bit		12.8
	No		4.8
Do you find Science easy, medium or difficult?	Easy	10.8	12.8
	Medium	86.5	66.0
	Difficult	2.7	12.8
	Depends	0.0	8.5
What activities do you do in Science that help you learn the most? (first activity students stated)	Practical work	51.4	29.8
	Demonstrations	2.7	10.6
	Listening Activities	0.0	10.6
	Reading Sheets	16.2	10.6
	Other*		

*Other		All had 5.4% each Video Clips Writing things down	All had 4.3% each Asking the teacher challenging questions Listening to teacher explanations
		All had 2.7% each Mnemonics Thinking About Science Worksheets Writing down from the board Writes most important facts down on a post-it	All had 2.1% each Activity Different book and pages given for independent revision Explanations on the board Graphs Labelling diagrams Reading through Research in the internet Worksheets Writing down from my head Writing down from the board
What activities do you do in Science that help you learn the most? (second activity students stated)	Reading Sheets	2.7	8.5
	Practicals	10.8	0.0
		5.4% Demonstrations	4.3% each Demonstrations Practical Worksheets
		2.7% Asking questions Graphs Sentence Starters	2.1% each Explanations on the board

		Teacher Explanations Worksheets	The teacher helping with the writing Writing down

Table 62 Year 8 students' responses to the question explain why your find the memory activities useful for your learning

a little bit - more so the listening activities as you are focused and that helps me take in more info that I remember
a bit because we can remember the science equipment
Because it gets your brain going
Because it helps me get better at listening skills
Because it helps me remember stuff and it teaches me the equipment
Because it helps your memory but I find it hard
because it practices your memory so I feel like I can remember things better
because of my short-term memory, it does help
because reading sheets helps me to remember key words e.g., oscillating, a list of facts I can remember for hw
easier to remember things
for the memory you learn more because the activities help you learn better
Half and half I learn the stuff in them whilst I doit but I don't remember afterwards
help you remember stuff and learn stuff in class
helps me remember but not as much as I would expect
Helps me remember in the lessons
helps me to remember all the apparatus, the reading sheets are good for information
Helps you concentrate, helps you remember
helps you get engaged like a warm up before we start

I can use it science but not in other lessons
I don't think it helps so much but is helping a bit
I think it helps you remember things better like when you do revision for the test you remember it better
If we had longer time on the reading sheets, I would learn more
in certain situations, yes (I don't normally remember but when I remember I remember faster, it has helped my memory
in some ways helping to remember things when it comes to revision
it can help you remember for class I think it would be less useful if you already had a good memory
it helps sometimes in science and in other lessons like RPE
it helps you to understand and memorise things mainly in science
it makes you remember all the equipment and stuff
Kind of sometime I there are too many instructions so I don't remember
No really, I don't feel like it helps me
not as good as teacher 3 last year. More instructions and I liked to write down facts from the reading sheets
Not just helped him with learning but helped him at home. As his memory is getting better, the id remembering more in other subjects and in is life at home
Not really, I just do them and forget about them
Reading sheets useful, Listening activities find it hard to focus when everyone is around you
Sometimes helps me remember stuff in other lessons specifically in French and maths and cooking at home
Sometimes it depends what we have to do. Big sets of instructions are the most help. We listen carefully to them all at one time.
The listening activities are a little bit useful the reading sheets are more useful
The listening activities do not help me with my memory the reading sheets helps as we can write stuff down in our books
They help you improve your memory and remembering instructions. I find them helpful in everything other lessons and at home
They improve, when you are in class you remember stuff for the next class

they make us remember information
This changes your mind. When the teacher tells you all the things you to hold them in your mind so when you do it, each time you do it faster
When we are doing practicals, it helps me remember stuff more
When we are doing practicals, it helps me remember what to do
Yes, a little bit because it helps us try to remember. Remembering sequences and pictures then helps in real life
Yes, because it increases our memory and it helps us learn over a period of time a fact, we had learned at the beginning
Yes, they help my memory. Builds up my memory. Remember stuff from writing down information from the reading sheets. Since year 7 this has helped me get a better memory.

Table 63 Year 8 Words that the active group students used to explain why they found memory activities useful

Active Student Common words in Responses to ***"Explain why you find the memory activities useful for your learning?"***	Number of times word was used in response
Remember	24
Memory	6
Reading Sheets	6
Other lessons	5
Listen(ing)	4
Learn	4
Science Equipment (Apparatus)	3
Science	3
Practicals	2

Focus(ed) Concentrate	2
Revision	2
More instructions in class	1
Brain	1
Do them at the start of lessons	1

Table 64 The Y8 Control Group Raw Data from the question why they find science easy, medium or difficult?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		4	10.8	10.8	10.8
	always liked science worked hard at it so I know quite a lot of what we're already doing	1	2.7	2.7	13.5
	depends on teaching method if teacher explaining works	1	2.7	2.7	18.9
	Because of the topics we study I already know and I really love science	1	2.7	2.7	16.2

	depends what subject you're doing e.g., electrons and something else depends which I understand I find Biology easier	1	2.7	2.7	21.6
	depends what you are doing some subjects are easier to get your head round	1	2.7	2.7	24.3
	I find it hard with physics, chemistry I find slightly easier and Biology I get	1	2.7	2.7	27.0
	I have always liked it and tried to find out lots about it	1	2.7	2.7	29.7
	I haven't always like science but I wanted to learn more so I started working harder and I am finding it easier now	1	2.7	2.7	32.4
	it is hard to remember the stuff as we have two different teachers	1	2.7	2.7	35.1
	more easy than difficult because the teacher explains things well and highlights key terms	1	2.7	2.7	37.8
	never been that good at science	1	2.7	2.7	40.5
	remembering stuff, I don't remember circuits and stuff from year 7	1	2.7	2.7	43.2
	so much stuff to remember and it is so complicated	1	2.7	2.7	45.9

	some lessons can be quite hard but some lessons can be quite easy as well.	1	2.7	2.7	48.6
	some of it is kind of confusing some of it isn't so I find chemistry the easiest and can ask older brother about the rest	1	2.7	2.7	51.4
	some of the words are quite similar and there are a lot of different words	1	2.7	2.7	54.1
	some stuff I find easier than others I find acids stuff easier than physics	1	2.7	2.7	56.8
	some stuff is easy to learn some stuff is more difficult	1	2.7	2.7	59.5
	Some stuff is really difficult to remember	1	2.7	2.7	62.2
	some topics are easier to learn than others, remembering stuff and trying to understand how it works	1	2.7	2.7	64.9
	some parts I understand and some we've already done are easier	1	2.7	2.7	67.6
	somethings are easier than others	1	2.7	2.7	70.3
	somethings are easy and somethings are difficult	1	2.7	2.7	73.0
	somethings come more easily and somethings you have to think about	1	2.7	2.7	75.7

	somethings I really understand and somethings I really struggle with	1	2.7	2.7	78.4
	sometimes I don't get it and sometimes I do	1	2.7	2.7	81.1
	sometimes I understand stuff it's easy, sometimes other stuff is hard	1	2.7	2.7	83.8
	sometimes it can be quite easy, mostly it is medium	1	2.7	2.7	86.5
	sometimes it's complicated sometimes straightforward	1	2.7	2.7	89.2
	sometimes it’s hard to understand and sometimes it is easy	1	2.7	2.7	91.9
	sometimes maybe it's not explained enough or too much detail gets a bit confusing	1	2.7	2.7	94.6
	there are somethings I really enjoy and somethings I struggle with	1	2.7	2.7	97.3
	tiny bit more than medium and did a lot at primary school	1	2.7	2.7	100.0

Table 65 The Y8 Active Group Raw Data from the question why they find science easy, medium or difficult?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		4	8.5	8.5	8.5
	a bit difficult you have to understand what happens in science like equations and stuff	1	2.1	2.1	10.6
	All the terms are hard	1	2.1	2.1	12.8
	as different aspects are easier	1	2.1	2.1	14.9
	Because I am getting high marks on my tests	1	2.1	2.1	17.0
	because there are some things, I find easier. Physics and chemistry I don't	1	2.1	2.1	19.1
	Because we cover topics, we have already covered it’s not that hard when you get your head around the vocabulary	1	2.1	2.1	21.3
	Certain subjects I am better at such as Biology, physics is more difficult	1	2.1	2.1	23.4
	Challenging and good	1	2.1	2.1	25.5
	challenging so we learn in it	1	2.1	2.1	27.7
	depends on what we are doing	1	2.1	2.1	29.8
	Depends on what we are doing	1	2.1	2.1	31.9
	depends on which topics and if I've done them before	1	2.1	2.1	34.0

	Depends what we are learning about it takes a long time for me to get something	1	2.1	2.1	36.2
	Easy to medium mix of topics and sometimes it's hard sometimes it is easy	1	2.1	2.1	38.3
	I don't really find biology easy to learn but the everything else I find easy	1	2.1	2.1	40.4
	I don't really get it and I'm not really good at science, finds following instructions difficult	1	2.1	2.1	42.6
	I don't understand it, physics is hard biology is medium	1	2.1	2.1	44.7
	I don't understand science e.g., difficult words and their meaning	1	2.1	2.1	46.8
	I don't understand some parts and others I do	1	2.1	2.1	48.9
	I enjoy it a lot and focus a lot	1	2.1	2.1	51.1
	I understand the practicals and the method e.g., periodic table is difficult to understand	1	2.1	2.1	53.2
	If find it pretty easy but I ask a lot of questions	1	2.1	2.1	55.3
	if it is new, it is medium if we are revisiting from year 7 it is easy	1	2.1	2.1	57.4
	in-between medium and easy	1	2.1	2.1	59.6
	it is challenging but within my abilities	1	2.1	2.1	61.7

	Maths, numbers, graphs are quite hard	1	2.1	2.1	63.8
	medium if new topics easy if we have already covered the topics, it depends what we are learning	1	2.1	2.1	66.0
	Most things I get	1	2.1	2.1	68.1
	Not easy or hard	1	2.1	2.1	70.2
	Science skills homework are sometimes quite hard	1	2.1	2.1	72.3
	some are difficult like physics whereas Biology is easier	1	2.1	2.1	74.5
	some elements are a bit more complex and some are less complex	1	2.1	2.1	76.6
	some of it is easy and some of it is confusing	1	2.1	2.1	78.7
	some of the practicals are hard to do	1	2.1	2.1	80.9
	some stuff I find really easy and other stuff more challenging	1	2.1	2.1	83.0
	Some subjects we do are really each and some are really hard	1	2.1	2.1	85.1
	some things are easier than others easier to learn physics than chemistry	1	2.1	2.1	87.2
	sometimes bits are hard sometimes it’s easy	1	2.1	2.1	89.4
	sometimes hard sometimes easy	1	2.1	2.1	91.5

	sometimes I find it easier e.g., biology and sometimes I find it harder	1	2.1	2.1	93.6
	sometimes the maths is hard	1	2.1	2.1	95.7
	sometimes you do hard sheets and we also easy ones	1	2.1	2.1	97.9

Table 66 The Y8 student response explaining why they find science easy, medium or difficult?

Response to question ***"Why do you find science easy/medium/difficult?"***	Control Group Frequency of response	Active Group Frequency of response
It is easy	1	4
Sometimes Science is easy and sometimes science is hard	13	18
Students find Science difficult	3	6
Student stated that a specific Science area was more difficult/easy than another	6	6
The teacher explains Science well	2	0
I like Science	3	1
Challenging & good	1	2
Other	6	5

Appendix F Data Analysis: Qualitative Data Tables and Notes from Year 7 & 8 Science Teacher, Science Teaching Assistants & Whole Staff Questionnaires

Appendix F contains qualitative data from Year 7 and Year 8 Science Teacher, Teaching assistants and whole staff questionnaires. The first section has Year 7 Science Teacher questionnaire responses; the second section has Y8 Science Teacher questionnaire responses; the third section the first- and second-year Science teaching assistants questionnaire responses and finally the fourth section includes the whole staff questionnaire responses from the first and second year of the research study.

Year 7 Science Teacher Questionnaire Responses and Notes

Analysis of the number of lessons the students in the study were exposed to Working Memory and related activities

Table 67 The teacher responses over the first three terms of the study to the statement "I follow the lesson structure to develop working memory"

Question	I follow the lesson structure to develop working memory									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7					2	3				

Term 2 Year 7					3	2		1		
Term 3 Year 7					3	2			1	

The Science teacher response to the statement ***I follow the lesson structure to develop Working Memory*** shown in Table 67, clearly shows that over the first year of the study the control group are not following the lesson structure to develop Working Memory and the active group are. One of the teachers in the active group struggled to dovetail the Working Memory structure into the lessons they delivered.

Table 68 The teacher responses over the first three terms of the study to the statement "I do 3 listening activities in a lesson"

Question	I do 3 listening activities in a lesson									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7					2	1	1			1 2 ev les
Term 2 Year 7					3	2				1 2 evles
Term 3 Year 7					3	1	1			1 2evles

The Science teacher response to the statement ***I do 3 listening activities in a lesson*** shown in Table 68 shows that over the first year of the study the control group did no listening activities.

Two of the active group teachers did regularly do 3 listening activities. The third active group teacher regularly did 2 listening activities, finding fitting three into a lesson difficult for their lesson delivery.

Table 69 The teacher responses over the first three terms of the study to the statement "The students read the differentiated reading sheets"

Question	The students read the differentiated reading sheets									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7			1		1	1	1	1		
Term 2 Year 7	1		1	1		2	1			
Term 3 Year 7		1	1	1		2		1		

The Science teacher response to the statement ***The students read the differentiated reading sheets*** shown in Table 69, over the first year of the study, shows the overall pattern; the control group are using the reading sheets less then active group. If this was a laboratory-controlled experiment then the control group would have no exposure to this part of the lesson structure. However, when a research study takes place in a school over two years then teachers will teach the lesson, they think are best for the students. All the teachers in the control group value the use of reading sheets.

Table 70 The teacher responses over the first three terms of the study to the statement "The students write down what they have learned with only the sentence starters to support them if needed"

Question	The students write down what they have learned with only the sentence starters to support them if needed									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7			1		1	2	1			
Term 2 Year 7			2		1	2		1		
Term 3 Year 7		1		2		2			1	

The Science teacher response to the statement ***The students write down what they have learned with only the sentence starters to support them if needed*** shown in Table 70, over the first year of the study shows the overall pattern; the control group students are writing down what they have learned less than the active group. This is what would be expected, as writing down what they have learned at the end of the lesson is part of the Working Memory structure. However, this is the most general teaching strategy that is included in the lesson structure to develop Working Memory, so it is not surprising that the control group Science teachers are using this strategy.

Table 71 The teacher responses over the first three terms of the study to the statement "I give students examples of memory techniques to help them with activities in the lesson"

Question	I give students examples of memory techniques to help them with activities in the lesson									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7				1	1			2	1	
Term 2 Year 7				3		2		1		
Term 3 Year 7					3		1	2		

The Science teacher response over the first year of the study to the statement ***I give students examples of memory techniques to help them with activities in the lesson*** is shown in Table 71. It is evident that the control group teachers are giving students examples of memory techniques much less frequently than the active group. This is an interesting observation because at the start of the study the teachers of the active group were asked explicitly to follow the lesson structure to develop Working Memory. However, they were not asked explicitly to give students examples of memory techniques. This is an interesting observation that might influence the metacognition of the students in the active group compared to the control group.

Table 72 The teacher responses over the first three terms of the study to the statement "After the listening activities I review the students' progress explicitly"

Question	After the listening activities I review the students' progress explicitly	
	Number of Control Group Science Teachers responses	Number of Active Group Science Teachers responses

	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 7					2	2				1
Term 2 Year 7					3	2	1			
Term 3 Year 7					3	1	1	1		

The Science teacher response over the first year of the study to the statement ***After the listening activities I review the students' progress explicitly*** is shown in Table 72. The control group teachers did not have the listening activities in their lessons so they would not be able to review the students' progress with the listening activities. The teachers in the active group were reviewing the student's progress explicitly with the listening activities. As with the previous statement; the active group teachers were not asked to review the students' progress with the listening activities (this means that after the listening activities the teachers go through what the students should have drawn or written on the symbols). However, as the first year of the study continued the active group teachers regularly reviewed the student's progress explicitly with the listening activities.

Table 73 The teacher responses over the first three terms of the study to the statement "Students are given opportunities to think about their memory and how it helps them to learn"

Question	Students are given opportunities to think about their memory and how it helps them to learn									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight

Term 1 Year 7				1	1	1		2		
Term 2 Year 7				1	2		2	1		
Term 3 Year 7				2	1		1	1	1	

The Science teacher response over the first year of the study to the statement ***Students are given opportunities to think about their memory and how it helps them to learn*** is shown in Table 73. Throughout the first year of the study the control group teachers gave the students fewer opportunities to think about their memory and how it helps them learn. In comparison to the active group teachers gave students more opportunities to think about their memory and how it helps them to learn. However, the active group teachers are doing this slightly less regularly towards the end of the first year of the study in comparison to the second and first term of the first year of study.

Analysis of Science teacher perceptions of the impact of the study over the first year of the study

Table 74 The Science teacher responses over the first three terms of the study to the statement "I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods"

Question	I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Term 1 Year 7	1		1			1			1	1
Term 2 Year 7		2	1				2			1
Term 3 Year 7		1	1		1	1		1		1

The Science teacher response over the first year of the study to the statement ***I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods*** is shown in Table 74**.** This is a deliberately ambiguous statement the responses also need to be taken the context of any further comments. *The control group teachers are more moderate in the way they have responded but disagree but overall disagree with the statement.* The active group teachers are divided in their response, however they become more extreme in their response over the first year of the study.

Table 75 The Science teacher responses over the first three terms of the study to the statement "I use activities to develop working memory with other year groups"

Question	I use activities to develop working memory with other year groups									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Term 1 Year 7		1			1			1	1	1
Term 2 Year 7			1	2					2	1
Term 3 Year 7				2		1			1	1

The Science teacher response over the first year of the study to the statement ***I use activities to develop working memory with other year groups*** is shown in Table 74. The majority of responses from all the Science teachers involved in the first year of the study was positive. The active group teachers were more positive than the control group teachers. Tables 75 and 76 show that the majority of the Science teachers are positive about the activities to develop Working Memory.

Analysis of the comments from the Science teacher questionnaire over the first year of the study

Table 76 The Science teacher comments in response to the Science teacher questionnaire over the first year of the study

Term	Control Group Science Teachers comments	Active Group Science Teacher comments
Term 1 Year 7	I do about 3-4 mins of mindfulness after a quick quiz at the start of the lesson. I call out the questions and then mark the questions together. (This teacher also said during the first term they used reading sheets once)	I am finding it difficult to do 3 explicit listening activities per lesson time wise
	No Comment	I would like to try and fit into GCSE & A-level
	Absent from school for number of weeks	Sc Teacher 2 can only fit in two listening activities every lesson – stated on sheet
Term 2 Year 7	*No Comment*	I only do one listening activity per lesson stated on sheet, I don't just write down what is learned but does other activities/mix it up
	teacher returning from maternity leave who has done action research into Working Memory and hence will skew control group responses positively	listening activities – doesn't do 3 but does do at least 1 every lesson
	No Comment	*No Comment*
Term 3 Year 7	Disagree reason given "depends on the student!"	Need longer lessons to fit in all activities – reading, listeningx3, prac, conclusion, learning
	Last question – put neutral agree – "looking forward to the results!"	*No Comment*
	No Comment	*No Comment*

The Science teacher comments from the control and the active group are shown in Table 76. The control group teachers were more moderate in their responses. The teacher in the first term commented that they doing mindfulness at the start of the lesson half way through the first year of study was covering maternity leave. The teacher returning from maternity leave had already been actively using Working Memory activities in lessons prior to the start of this study. There is some evidence that mindfulness has an impact on Working Memory (e.g., Chambers, Chuen Yee Lo, & Allen, 2008) and the teacher returning from maternity leave used the reading sheets regularly. Hence, this questionnaire enables there to be transparency about the Science lesson experiences of the students in control group.

The majority of the comments of the Science teachers in the active group during the first year of the study were from two of the teachers. These comments were about on the number of listening activities they do during a lesson. The active group teachers were asked to do three listening activities during every lesson. It is evident that two of the three teachers struggling to complete three listening activities in a lesson. One of the teachers did two listening activities every lesson, this is confirmed from the lesson observation data from the first year. The other teacher states that they do at least one every lesson. This comment is contradicted by the data from the student interviews. The students stated that they used to do them every lesson and had found them useful. However, there Science teacher had used them less often in the third term of the first year. Furthermore, this teacher also stated that the students sometimes write down what they have learned at the end of the lesson but other activities are also used instead of this in some lessons.

One of the active group teachers stated that “I would like to try and fit into GCSE & A-level” this indicates the teacher’s belief that the lesson structure to develop Working Memory was having a positive impact on Working Memory. This is coupled with the same teacher stating they agree that the lesson to develop Working Memory has the same impact as a normal way of teaching lesson. On the other hand, the teacher who stated that they disagree with the same statement was completing the lesson structure to develop working memory every lesson; with the exception that the teacher was doing two listening activities instead of three every lesson.

The responses of the teachers in the first year of the research study shine a spotlight on the experience of the students. The Science teacher responses alongside the responses to the student interviews gives the study transparency. Providing a clear picture of the experiences of the active and control group students.

Year 8 Science Teacher Questionnaire Responses and Notes

Table 77 Science Teacher responses in Year 8 to the statement I follow the lesson structure to develop WM

Question	I follow the lesson structure to develop WM									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8					4	2	1			
Term 2 Year 8					3	1		1		
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 78 Science Teacher responses in Year 8 to the statement I do 3 listening activities a lesson

Question	I do 3 listening activities a lesson									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8					4		1		1	1
Term 2 Year 8					3			1		1

Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 79 Science Teacher responses in Year 8 to the statement The students read the differentiated reading sheets

Question	The students read the differentiated reading sheets									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8			1	2	1	1	1	1		
Term 2 Year 8		2			1		2			
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 80 Science Teacher responses in Year 8 to the statement I give students examples of memory techniques to help them with activities in the lesson

Question	The students write down what they have learned with only the sentence starters to support them if needed									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8	2		1		1		1		1	1
Term 2 Year 8			2		1			1		1
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 81 Science Teacher responses in Year 8 to the statement I give students examples of memory techniques to help them with activities in the lesson

Question	I give students examples of memory techniques to help them with activities in the lesson									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8				2	2				2	1
Term 2 Year 8			1		2			2		
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 82 Science Teacher responses in Year 8 to the statement After the listening activities I review the students' progress explicitly

Question	After the listening activities I review the students' progress explicitly									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8					4		1	1	1	
Term 2 Year 8					3		1		1	
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 83 Science Teacher responses in Year 8 to the statement Students are given opportunities to think about their memory and how it helps them learn

Question	Students are given opportunities to think about their memory and how it helps them learn

	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
Term 1 Year 8				2	2			2		0
Term 2 Year 8			1	2				2		
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 84 Science Teacher responses in Year 8 to the statement I think the lesson structure to develop WM has the same impact on attainment as teaching science with traditional methods

Question	I think the lesson structure to develop WM has the same impact on attainment as teaching science with traditional methods									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Term 1 Year 8			2	2				3		
Term 2 Year 8		2		1				1	1	
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

Table 85 Science Teacher responses in Year 8 to the statement I use activities to develop WM with other year groups

Question	I use activities to develop WM with other year groups									
	Number of Control Group Science Teachers responses					Number of Active Group Science Teachers responses				
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Strongly disagree	Disagree	Neutral	Agree	Strongly agree

Term 1 Year 8			1	3				1	2	
Term 2 Year 8				3					2	
Term 3 Year 8	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID	COVID

First Year of Study Analysis of the Science Teaching Assistant Questionnaire

The teaching assistants that were regularly supporting Science lessons during the first year of the study filled out a questionnaire. The results of the questionnaire (Appendix G) are shown in Table 86 It would not be possible to conclude anything from the limited data collected. However, it is able to shine light on the experience of the active and control students when coupled with the data from the student and Science teacher questionnaire from the first year of the study. The data for the active group teaching assistants is only with the class where the teacher stated they were struggling to complete all three listening activities in the lesson. The teaching assistant comments and questionnaire response indicate that the active group teacher for this class was adhering to the lesson structure less than they indicated on the teacher questionnaire. This is also supported by the data from the student interviews. Alongside this is the responses that indicate that the control group teachers are broadly not following the lesson structure to develop Working Memory. This data gives further supports the transparency of the experience the active group students have had during the first year in comparison to the control group students.

Table 86 The Science teaching assistants' responses to the questionnaire in the first year of the study

Active or Control Group Class	I support students with the differentiated sheets	I support students with the writing down what they have learned at the end of the lesson	I think the lesson structure to develop wm has the same impact on attainment as teaching science with traditional teaching methods	The students I support have seen an improvement in their memory skills since the start of the research study	Further Comments
Control	0/6 lessons per fortnight	2-1/6 lessons per fortnight	Neutral	Neutral	I am only in one lesson per fortnight with one class
Active	0/6 lessons per fortnight	5/6 lessons per fortnight	Agree	Disagree	TA spoke to me after filling out the questionnaire as they wrote disagree because the teacher of this active group class has not been doing the WM activities regularly in the lessons as requested by the researcher. When supporting in researchers Yr8 class where activities are used real benefits were seen to SEND students completing WM activities
Both	2-1/6 lessons per fortnight	2-1/6 lessons per fortnight	Neutral	Neutral	

Second Year of Study Analysis of the Science Teaching Assistant Questionnaires

Table 87 The Science Teaching Assistant Questionnaire Responses for the Second Year of the Study (year 8 students)

Science TA Number (class worked with)	I support students with the differentiated sheets	I support students with the writing down what they have learned at the end of the lesson	I think the lesson structure to develop wm has the same impact on attainment as teaching science with traditional teaching methods	The students I support have seen an improvement in their memory skills since the start of the research study	Further Comments – answered just for student as other Qre completed at same time for whole class imp.context
7B	5/6 lessons per fortnight	5/6 lessons per fortnight		Agree	Not answer “same impact” Q. The students have enjoyed the activity for WM they have discussed and seem to challenge themselves and to all extent their peers. The student I support has taken part on the computer but not on paper. (The student) has autism.
5B			Disagree	Neutral	Not answered the first 2 Qs – could be confused about the Questionnaire
8C	2-1/6 lessons per fortnight	2-1/6 lessons per fortnight	Disagree	Disagree	TA has filled in Qre in respect to just student she supports (only supports student 1-2 lessons fortnight) “Student struggles to listen to instructions”

4C	2-1/6 lessons per fortnight	2-1/6 lessons per fortnight	Strongly disagree	Strongly disagree	TA has filled in Qre in respect to just student she supports (only supports student 1-2 lessons fortnight) “No change in this student as (student) fails to listen to any instructions – too busy playing/messing around, peculiar noises etc
6D	0/6 lessons per fortnight	0/6 lessons per fortnight	Neutral	Neutral	

First Year of Study Analysis of the Whole School Staff Questionnaire Responses

The whole school staff was invited to complete a questionnaire (Appendix G). The statements the staff were asked to respond to are listed below:

- How do you come into contact with Year 7 Students? (job role can be circled or there was another option)

The statements below had three options yes, don’t know, no

- I have heard of working memory
- I am aware that working memory is linked to learning
- I have spoken to Year 7 students this year informally about memory
- I have led an activity in a class, tutor time or assembly about memory this year with Year 7s
- I use working memory activities with the current Year 7 students

- I think developing working memory has a positive impact on learning
- I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students
- This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (not Year 7)
- I think the science lesson structure to develop working memory has the same impact as traditional teaching methods
- I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods

The whole staff questionnaire responses were analysed separated in two groups, school support staff and school teaching staff.

Analysis of the support staff responses to the whole school staff questionnaire for the first year of the study

There was a total of 33 support staff who completed the whole school staff questionnaire from a wide range of job roles where these colleagues come into contact with Year 7 students (Table 88). A decision was taken to not give the cleaners or the canteen staff the whole staff questionnaire. This was because the cleaners do not work during school hours and the canteen staff have limited contact with the Year 7s as our canteen serving system is so fast.

Table 88 The range of different roles of how the support staff come into contact with Year 7 students

Roles stated as having contact with Year 7	Frequency	Percent
Cover supervisor	1	3.0
Exams officer	1	3.0
Learning Coach	1	3.0

Learning Coach/student support	1	3.0
not stated	2	6.1
PA to Head of 6th form	1	3.0
Site manager	1	3.0
SLT - business manager	1	3.0
Student support	4	12.1
Support staff in other capacity	5	15.2
Support staff in other capacity, run club year 7s attend	1	3.0
Support staff in other capacity	2	6.1
TA/Tutor/Keyworker	1	3.0
Teaching assistant	2	6.1
Teaching assistant tutor student support run a club year 7 attend key worker skills for learning activities	1	3.0
Teaching assistant/key worker	3	9.1
Teaching assistant/key worker skills for learning activities	3	9.1
Technician	1	3.0
Tutor/student support	1	3.0

Table 89 The support staff responses to the statements in the first year of study whole staff questionnaire

Statement	Support Staff Response to Statements (Percentage %*)

	Yes	Don't Know	No
I have heard of working memory	63.6		30.3
I am aware that working memory is linked to learning	63.6	3.0	27.3
I have spoken to Year 7 students this year informally about memory	18.2	3.0	72.7
I have led an activity in a class, tutor time or assembly about memory this year with Year 7s			90.9
I use working memory activities with the current Year 7 students	3.0		90.9
I think developing working memory has a positive impact on learning	66.7	21.2	6.1
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students	30.3	12.1	51.5
This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (**not** Year 7)	21.2	12.1	60.6
I think the science lesson structure to develop working memory has the same impact as traditional teaching methods	6.1	69.7	18.2
I think the science lesson structure to develop working	3.0	69.7	21.2

memory has a positive impact on attainment compared to traditional teaching methods			

*Some of the percentages do not add up to 100 as some members of support staff did not answer that specific question

Table 90 The support staff comments on the whole staff questionnaire

Comments
I work one to one or with a class sometimes
Really impressed how (named science teacher 1) has identified those children who benefit from power point print outs in advance of lesson. Gives students a visual guide to ease load on their WM. As someone with a low WM this worked for me during my degree course. Would like to see this used in other lessons.

The support staff who responded to the whole staff questionnaire were broadly representative of job roles within the research school. There were 33 responses and Table 88 shows a minimum of ten different job roles represented in those individuals who responded. The research school has a policy that any member of staff support or teaching staff can be a form tutor. Table 89 shows that the majority of support staff have heard of Working Memory and that it can be linked to learning. Only 18.2% of support staff had spoken informally to Year 7s about memory. Furthermore, a large majority 90.9 had not led a memory-based activity with students nor had they used Working Memory activities with the Year 7 students. However, there was one person who has been leading Working Memory activities with the current Year 7. Also, there was a large majority of support staff think that developing Working Memory has a positive impact on learning.

In response to the question "*I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students*". 30.3% of the support staff had seen a colleague using Working Memory activities with Year 7 students, and 51.5% had not seen a colleague using Working Memory activities with Year 7 students. There responses are slightly different for the question "*This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (not Year 7)"* with 21.2 % answering "*yes"* and 60.6% responding *"no".*

The last two questions in the questionnaire were linked. The first question being worded neutrally; "I think the science lesson structure to develop working memory has the same impact as traditional teaching methods." The last question was positively skewed; "I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods.". The responses to both questions were very similar. The "don't know" response was identical; 69.7% for both questions. The "no" response increased from 18.2% to 21.2%; the "*yes"* response declines by the same percentage from 6.1% to 3.0%. So overall, the support staff are not sure if the Working Memory lesson structure is better for Science attainment. A small minority think that the Working Memory lesson structure has a positive impact on Science attainment.

Holistically the response of the support staff to the whole staff questionnaire shows that most of the support staff are aware of Working Memory and its' links to learning. Furthermore, the questionnaire results indicate that the support staff think that developing working memory has a positive impact on learning. Only a small number of support staff have been involved in memory activities or working memory activities with the Year 7 students. The data also indicates that the support staff have seen very few non-Science colleagues delivering Working Memory activities to Year 7 students. This clearly indicates that there is some leakage of Working Memory activities in non-Science domains within the school to the control group students. This information is important for the transparency of this research study and will need to be considered when discussing the findings of the study.

Analysis of the teaching staff responses to the whole school staff questionnaire for the first year of the study

There was a total of 48 teaching staff who completed the whole school staff questionnaire from a wide range of job roles that came into contact with Year 7 during the first year of the study (Table 91). This is a broadly representative number for the teaching staff at the school (approximately 120 full and part time)

Table 91 The range of different roles of how the teachers came into contact with Year 7 students during the first year of the study

Roles stated as having contact with Year 7	Frequency	Percent
Left Blank	1	2.1
Anonymous	1	2.1
Head of House	1	2.1
Head of House and Teacher	2	4.2
Run a Year 7 Club	1	2.1
SLT	3	6.3
SLT & other	2	4.2
Teacher	30	62.5
Tutor	1	2.1
Teacher and a tutor	3	6.3
Teacher & Run a club Year 7s attend	1	2.1
Teacher, Run a club Year 7s attend and a tutor	1	2.1

Teacher, Run a club Year 7s attend, tutor and run skills for learning activities with Year 7s	1	2.1

Table 92: The teaching staff responses to the statements in the first year of study whole staff questionnaire

Statement	Teaching Staff Response to Statements (Percentage %*)		
	Yes	Don't Know	No
I have heard of working memory	100	0	0
I am aware that working memory is linked to learning	100	0	0
I have spoken to Year 7 students this year informally about memory	64.6	0	35.4
I have led an activity in a class, tutor time or assembly about memory this year with Year 7s	47.9	0	50.0
I use working memory activities with the current Year 7 students	41.7	2.1	56.3

I think developing working memory has a positive impact on learning	83.3	14.6	2.1
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students	35.4	4.2	60.4
This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (**not** Year 7)	31.3	6.3	60.4
I think the science lesson structure to develop working memory has the same impact as traditional teaching methods	18.8	79.2	2.1
I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods	31.3	66.7	2.1

*Some of the percentages do not add up to 100 as some members of teaching staff did not answer that specific question

Table 92 shows teacher responses to the whole staff questionnaire. The teachers who responded to the questionnaire are aware of Working Memory and its' link to learning. There is a slight decline (of 16.7% down to 83.3%) in the percentage of teachers who think developing Working Memory can have a positive impact on learning. However, the teacher opinion shifts to the majority of teachers responding *"don't know"* to the lesson structure to develop Working Memory statements ("I think the science lesson structure to develop working memory has the same impact as traditional teaching methods" and "I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods") . The teacher response is similar to both statements relating to the lesson structure to develop Working Memory's impact on learning. There is a slight shift to the "*yes*" response (from 18.8% to 31.3%) for the lesson structure to develop Working Memory has a positive impact on attainment compared to traditional teaching methods.

The majority of teachers have talked to Year 7 students about memory (64.6%), however this decline to a large minority of teachers running activities about memory with Year 7 students (47.9%). A sizeable minority of teachers are delivering WM activities in their Year 7 lessons and in lessons with other year groups; 41.7% and 35.4% respectively. This is supported by 30.7% and 29.4% (Table 49) of the control group stating they had experienced Working Memory activities in other lessons; at the start and the end of the first year of the study respectively. Furthermore, 30.3% (Table 138) of support staff stated they had seen colleagues delivering Working Memory activities in other lessons.

Table 93 The teaching staff comments on the whole staff questionnaire

Teaching staff comments written on the whole staff questionnaire
Clearly a vital component of students' ability to function in a classroom. As a department (Geography) we have used/are using some strategies as outlined by researcher in inset
Weekly activities based around WM and Auditory Processing
Not possible to comment on colleagues as a full-time teacher, I am encouraging the Maths Department to do them though! Year 7 do WM activities every lesson.
I have used WM activities extensively in previous years but am not timetabled with Yr7 this year.
Working Memory probably has more impact
I have observed another teacher in the department doing WM activities. I know what I do makes a difference as ever they don't always transfer these skills from subject to subject.
I have observed another teacher in the department using Working Memory activities

I used Auditory Memory tasks in Autumn term 1 as part of once a week writing lessons
Mindfulness & Meditation club/yr. 7 mindfulness meditation 10 x lessons, I know there are links between mindfulness and WM as you know we have a number of year 7 mindfulness leaders does wm practice influence wm? I have written don't know but as you LOVE WM, I am sure that it has an impact. I guess if quizzed further I recognise that our mind or brain has plasticity that we can develop its wm? its capacity? I may be wrong
Uses some WM activities. I have not observed a science lesson structure myself but I have heard about how they structure their lessons and we have trialled different activities on inset days that I have tried out in class.
We do a lot of work in MFL on learning strategies for vocab/presentations. I'm not sure if this comes under the title "working memory".
Would like to know more about it. Also use the similar working memory activities with other year groups - or what I understand by it
I think it is remarkable and have seen the impact on the current year 8s. I would like to use it in my sessions but realistically need a "go to" area I can dip into without lots of additional thought or time. (within tick part of questionnaire indicated they had observed a teaching assistant using WM activities this year)
Don't know yet! Await the findings of the research!

Table 93 shows comments written by teachers. There are several subject areas where at least one teacher is delivering Working Memory activities; these are English, Mathematics and Geography. A teacher of Modern Foreign Languages (MFL) has stated that MFL teachers use a lot of strategies for learning vocabulary and completing presentations. Furthermore, in the Religion, Philosophy and Ethics (RPE) department in Year 7 they teach students about mindfulness and students are invited to take part in guided mindfulness meditations in ten formally taught lessons but also can attend a mindfulness club that runs for all staff and students every lunchtime. There is evidence to support the link between mindfulness and Working Memory (e.g.,Chambers, Chuen Yee Lo, & Allen, 2008). So, it is important to consider its' possible impact on leakage to students in the control group.

Holistically (Tables 91-94) all the teachers who responded had heard of Working Memory, and its' link to learning. A large majority of teachers (81.3% from Table 93) thought that developing Working Memory has a positive impact on learning. However, the majority teacher response shifted to "*don't know"* when asked about the lesson structure to develop Working Memory. There was a slight shift from the "*don't know"* response to "*yes"* when asked "I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods". This shows that although there is good awareness of Working Memory and its' link to learning; some of which is transferred to activities in lessons. There is a more neutral response to the lesson structure to develop Working Memory that the research is focused on.

The majority of teachers who responded to the questionnaire had some contact with Year 7. A large majority had spoken to Year 7 students about memory (64.6% Table 92) and a large minority had run activities about memory with Year 7 students (47.9% Table 92). When teachers were asked more specifically about conducting Working Memory activities with students. A large minority were doing Working Memory activities (41.7% Table 92) with Year 7 students, with lower percentages reporting observing colleagues doing Working Memory activities with Year 7 (35.4% Table 92) and with students in other year groups (31.3% Table 92). Teachers of the English, Mathematics and Geography departments all stating Year 7 experience Working Memory activities in at least some of their lessons. Furthermore, the RPE department stating that the Year 7s do a 10-lesson mindfulness course and that Year 7s attend a lunchtime mindfulness club. There is evidence to support the link between mindfulness and Working Memory (e.g.,Chambers, Chuen Yee Lo, & Allen, 2008). Also, the MFL department do many activities in their lessons to help Year 7 students remember vocabulary and presentations.

These responses shine a spotlight on to the whole school memory and Working Memory experiences of the students in the first year of the study. The vast majority of the teaching staff think that developing Working Memory has a positive impact on learning. However, this majority is not reflected in way they deliver their lessons to Year 7s and other Year groups. This shows the possible extent of the leakage in the control group students to Working Memory activities in other subject areas around the school. The leakage to the control group students is supported by the responses to the teacher, support staff and student questionnaires. The triangulation of the support staff, teacher and student response provides further transparency to the research study.

Second Year of Study Analysis of the Whole School Staff Questionnaire Responses

Table 94 Further comments made by the teachers on the Year 8 Whole Staff Questionnaire

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		55	82.1	82.1	82.1
	Although I don't teach Yr 8 this year (next to teacher ticked). Good Luck with the research - I'd be really interested to read the results!	1	1.5	1.5	83.6

	As a PE teacher I do this much more in theory lessons with Y12/13 students! (on doing WM activities with Y8 students has ticked Yes very occasional)	1	1.5	1.5	85.1
	doesn't teach year 8 this year but is a HOD so has contact with them	1	1.5	1.5	86.6
	I 100% agree with and see the relevance of investing in working memory. I personally feel I see a better impact on learning when tasks are linked to the lesson (i.e., using ideas/concepts etc which are being explored in the lesson/s)	1	1.5	1.5	88.1
	I think developing WM has a positive impact on learning (ticked Y and DON'T KNOW written - needs more evidence)	1	1.5	1.5	89.6
	I think it would be useful to know how increase in WM impacts long term memory in terms of revision ideas and I would like to know a bit more about the science behind it	1	1.5	1.5	91.0
	I'd love some really simple ways of using this in Art and Life Skills	1	1.5	1.5	92.5

	It is excellent, thanks	1	1.5	1.5	94.0
	The kind of thing we do is focused on visual/auditory memory (listen and read facts knowing you will have recall 6 facts after the slides have gone) Sorry Mel - I'm not sure this is working memory	1	1.5	1.5	95.5
	Tried it in a Science cover lesson a few years ago	1	1.5	1.5	97.0
	We do retrieval learning quizzes in RPE. I am not sure of the empirical evidence but I know that students value these tasks as students respond well and I enjoy it too!	1	1.5	1.5	98.5
	Would be interested in learning more (thanks just heard Weds 18th March see you there)	1	1.5	1.5	100.0

Appendix G: Questionnaires and Observation Forms

Introduction to Appendix G

Appendix G contains copies of the questionnaires that the students, Science teachers, Science teaching assistants and whole staff questionnaires filled in during the study. There is also the form used for the lesson observation and student interview form

Year 7 Science Staff Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 7 Staff Science Questionnaire for class 7______

	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
I follow the lesson structure to develop working memory					
I do 3 listening activities in a lesson					
The students read the differentiated reading sheets					
The students write down what they have learned with only the sentence starters to support them if needed					
I give students examples of					

memory techniques to help them with activities in the lesson					
After the listening activities I review the students progress explicitly					
Students are given opportunities to think about their memory and how it helps them to learn					

Year 7 Science Teachers Opinion of the lesson structure

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods					
I use activities to develop working memory with other year groups					

Add any further comments below (continue over the page if necessary)

Year 7 Student Science Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

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Year 7 Student Science Questionnaire Name ______________ Class 7____

	Yes ☺	A bit 😐	No ☹
I can remember information from lessons really well			
I think that having a good memory is important for learning			
I think having a good memory is part of being intelligent			
In science lessons I do activities to			

practice using my memory			
In other subjects I do activities to practice using my memory			
I use the memory skills I practice in Science in other subjects			
I am learning new information and skills in Science			
I have a good memory			
I am intelligent			

Add any further comments below – continue over the page if you need to

Year 7 Science Teaching Assistant Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 7 Teaching Assistant Science Questionnaire Name: ________________________________

I support students in 7 ____ & 7______ & 7____

	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
I support students with the differentiated reading sheets					
I support students with the writing down what they have learned at the end of the lesson					

Year 7 Teaching Assistants Opinion of the lesson structure

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think the lesson structure to develop working memory has the same impact					

on attainment as teaching science with traditional teaching methods					
The students I support have seen an improvement in their memory skills since the start of the research study					

Add any further comments below (continue over the page if necessary)

Year 7 Whole Staff Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously, that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 7 Staff Questionnaire Name________________________________

Part One: How do you come into contact with Year 7 Students? (Please tick all that apply)

SLT in a Pastoral/other Capacity Teaching Assistant

Head of House Tutor

Student Support Run a club Year 7s attend

Teacher Skills For Learning Activities

Key Worker

Support Staff in another capacity (e.g., taking payments from students, help find lost property)

	Yes	No	Don't Know
I have heard of working memory			
I am aware that working memory is linked to learning			
I have spoken to Year 7 students this year informally about memory			
I have led an activity in a class, tutor time or assembly about memory this year with Year 7s			
I use working memory activities with the current Year 7 students			
I think developing working memory has a positive impact on learning			
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7 students			

This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (**not** Year 7)			
I think the science lesson structure to develop working memory has the same impact as traditional teaching methods			
I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods			

Add any further comments below (continue over the page if necessary)

Year 7 Lesson Observation & Student Interview Form

Lesson Observation

Date: **Class: 7__** **Lesson Time: first third/second third/last third**

Activities in Classroom	**Frequency**
Listening activity to develop working memory	
Reading differentiated reading sheets	
Writing down with only the support of starter sentences what has been learned in the lesson	
Teacher talking about memory	
Students talking about memory	
Normal teaching strategy	

Student Interview (2 randomly chosen students)

Student 1: ___________________________

Question	Response
Do you do memory activities in your science class?	
If yes: Do you think doing memory activities in your science class is useful for your learning?	
If yes: Why	
Do you find it easy or difficult to learn in Science?	
Why?	
What activities do you do in Science that help you learn the most?	

Student 2: ________________________

Question	Response
Do you do memory activities in your science class?	
If yes: Do you think doing memory activities in your science class is useful for your learning?	
If yes: Why	
Do you find it easy or difficult to learn in Science?	
Why?	
What activities do you do in Science that help you learn the most?	

Observations or notes from the lesson or speaking to the two students

Year 8 Science Staff Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 8 Staff Science Questionnaire for class 8______

	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
I follow the lesson structure to develop working memory					
I do 3 listening activities in a lesson					
The students read the differentiated reading sheets					
The students write down what they have learned with only the sentence starters to support them if needed					
I give students examples of memory techniques to help them with activities in the lesson					
After the listening activities I review the students progress explicitly					
Students are given opportunities to think about their					

memory and how it helps them to learn					

Year 8 Science Teachers Opinion of the lesson structure

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think the lesson structure to develop working memory has the same impact on attainment as teaching science with traditional teaching methods					
I use activities to develop working memory with other year groups					

Add any further comments below (continue over the page if necessary)

Year 8 Student Science Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 8 Student Science Questionnaire Name ______________ Class 8____

	Yes ☺	A bit 😐	No ☹
I can remember information from lessons really well			
I think that having a good memory is important for learning			
I think having a good memory is part of being intelligent			
In science lessons I do activities to			

practice using my memory			
In other subjects I do activities to practice using my memory			
I use the memory skills I practice in Science in other subjects			
I am learning new information and skills in Science			
I have a good memory			
I am intelligent			

Add any further comments below – continue over the page if you need to

Year 8 Science Teaching Assistant Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 8 Teaching Assistant Science Questionnaire Name: ___________________________________

I support students in 8 ____ & 8______ & 8____

	Practically every lesson	5/6 lessons per fortnight	4-3/6 lessons per fortnight	2-1/6 lessons per fortnight	0/6 lessons per fortnight
I support students with the differentiated reading sheets					
I support students with the writing down what they have learned at the end of the lesson					

Year 8 Teaching Assistants Opinion of the lesson structure

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I think the lesson structure to develop working memory has the same impact					

on attainment as teaching science with traditional teaching methods					
The students I support have seen an improvement in their memory skills since the start of the research study					

Add any further comments below (continue over the page if necessary)

Year 8 Whole Staff Questionnaire

Thank you for agreeing to fill out this short questionnaire. Please be aware that although I have asked for names these will be only used by me to give the information you pass on some context. If you would prefer to fill out the questionnaire anonymously, that is fine.

DATA PROTECTION NOTICE: The information given will be used for research purposes only and your personal data will be processed in accordance with current data protection legislation and the University of Exeter's notification lodged at the Information Commissioner's Office. Your personal data will be treated in the strictest confidence and will not be disclosed to any unauthorised third parties. The results of the research will be published in anonymised form.

Year 8 Staff Questionnaire Name_________________________________

Part One: How do you come into contact with Year 8 Students? (Please tick all that apply)

SLT in a Pastoral/other Capacity Teaching Assistant

Head of House Tutor

Student Support Run a club Year 8s attend

Teacher Skills For Learning Activities

Key Worker

Support Staff in another capacity (e.g., taking payments from students, help find lost property)

	Yes	No	Don't Know
I have heard of working memory			
I am aware that working memory is linked to learning			
I have spoken to Year 8 students this year informally about memory			
I have led an activity in a class, tutor time or assembly about memory this year with Year 8s			
I use working memory activities with the current Year 8 students			
I think developing working memory has a positive impact on learning			
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 8 students			

This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (**not** Year 8)			
I think the science lesson structure to develop working memory has the same impact as traditional teaching methods			
I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods			

Add any further comments below (continue over the page if necessary)

Year 8 Lesson Observation & Student Interview Form

Lesson Observation

Date: **Class: 8__** **Lesson Time: first third/second third/last third**

Activities in Classroom	**Frequency**
Listening activity to develop working memory	
Reading differentiated reading sheets	
Writing down with only the support of starter sentences what has been learned in the lesson	
Teacher talking about memory	
Students talking about memory	
Normal teaching strategy	

Student Interview (2 randomly chosen students)

Student 1: _________________________

Question	Response
Do you do memory activities in your science class?	
If yes: Do you think doing memory activities in your science class is useful for your learning?	
If yes: Why	
Do you find it easy or difficult to learn in Science?	
Why?	
What activities do you do in Science that help you learn the most?	

Student 2: _________________________

Question	Response
Do you do memory activities in your science class?	
If yes: Do you think doing memory activities in your science class is useful for your learning?	
If yes: Why	
Do you find it easy or difficult to learn in Science?	
Why?	
What activities do you do in Science that help you learn the most?	

Observations or notes from the lesson or speaking to the two students

Appendix H: Data from Chapter 4 not directly linked to the key findings of the study

H:4.1.2 A comparison of the control and the active group Pre-test Means & Standard Deviation for WM and Science Attainment

The active and control group for the pre-test (baseline) Working Memory tests and Science attainment assessments had similar means and overlapping standard deviations (Tables 95-97). Hence, comparing these baseline measurements with measurements of Working Memory and attainment taken later on in the study is a fair comparison. This would give clear indication of the efficacy of the Working Memory activities to increase Working Memory and hence Science attainment.

Table 95 The Working Memory Assessments pre-test means and standard deviations for both the control group and the active group

WM Component Assessed	Control Group			Active Group		
	N	Mean	SD	N	Mean	SD
Word Recall	83	103.868	13.500	79	104.354	10.550
Pattern Recall	83	97.554	10.986	79	98.987	11.157
Counting Recall	83	100.615	17.083	79	100.051	16.235
WM Composite	83	102.241	12.928	79	102.595	10.484
WM Processing Speed	83	92.699	11.472	78	94.756	10.332

Table 96 The Science Investigation Skills Assessments pre-test means and standard deviations for both the control group and the active group

Science Attainment Component Assessed	Control Group	Active Group

	N	Mean	SD	N	Mean	SD
Investigation Planning Skills	84	7.3107	0.10415	81	7.4235	0.07949
Investigation Obtaining Evidence Skills	57	7.3649	0.13950	80	7.3938	0.10948
Investigation Analysing Data Skills	83	7.3807	0.11735	86	7.4395	0.08849
Investigation Evaluation Skills	63	7.3365	0.09887	76	7.3842	0.09529

Table 97 The Science Assessments for Home Work and Summative Science Test 1 pre-test means and standard deviations for both the control group and the active group

Science Attainment Component Assessed	Control Group			Active Group		
	N	Mean	SD	N	Mean	SD
Physics Assessed Home Work 1a	58	7.447	0.131	54	7.463	0.209
Physics Assessed Home Work 1b	53	7.385	0.139	50	7.370	0.161
Physics Assessed Home Work 1c	56	7.425	0.144	50	7.398	0.193
Chemistry Assessed Home Work 1a	56	7.388	0.128	57	7.418	0.123
Chemistry Assessed Home Work 1b	56	7.479	0.170	57	7.581	0.156
Biology Assessed Home Work 1a	57	7.349	0.176	55	7.409	0.217
Biology Assessed Home Work 1b	40	7.305	0.154	32	7.450	0.230
Year 7 Test 1	59	7.432	0.111	86	7.409	0.0849

H: 4.1.3 A Comparison of Pre-test and Post-test means and standard deviations of the WM and Science attainment components assessed

An independent-samples t-test was conducted to compare the Post-test Word Recall of the WM Assessment in the control and active group conditions. There was not a significant difference in the scores for control group (M=105.1220, SD=14.44563) and the active group (M=104.9756, SD=12.85049) conditions; t(162)=-0.069, p=.945

An independent-samples t-test was conducted to compare the Post-test Pattern Recall of the WM Assessment in the control and active group conditions. There was not a significant difference in the scores for control group (M=100.5366, SD=11.23948) and the active group (M=102.7561, SD=9.96359) conditions; t(162)=1.338, p=.183

An independent-samples t-test was conducted to compare the Post-test Counting Recall of the WM Assessment in the control and active group conditions. There was not a significant difference in the scores for control group (M=104.3171, SD=18.76619) and the active group (M=104.6098, SD=18.58830) conditions; t(162)=-0.100, p=.920

An independent-samples t-test was conducted to compare the Post-test WM Composite of the WM Assessment in the control and active group conditions. There was not a significant difference in the scores for control group (M=105.2927, SD=14.84196) and the active group (M=105.9390, SD=12.03426) conditions; t(162)=-0.306, p=.760

An independent-samples t-test was conducted to compare the Post-test WM Processing Speed of the WM Assessment in the control and active group conditions. There was not a significant difference in the scores for control group (M=95.9012, SD=12.02664) and the active group (M=96.5802, SD=11.10052) conditions; t(162)=-0.373, p=.709

Table 98 The Science Assessment Summative Science Test 1, the pre-test and subsequent post-test Science Assessment summative tests showing the mean & standard deviations for both the control group and the active group

Science Attainment Component Assessed	Control			Active		
	N	Mean	SD	N	Mean	SD
Pre-test Y7 Test 1	59	7.432	0.111	86	7.409	0.085
Post-test Y7 Test 2	89	7.469	0.095	59	7.439	0.110
Post-test Y7 Test 3	53	7.447	0.0868	90	7.416	0.0806
Post-test Y7 End of Year Test	58	7.435	0.124	85	7.437	0.113

Post-test Y7 End of Year Report grade	91	7.460	0.120	90	7.452	0.121
Post-test Y8 Test 1	90	7.636	0.134	86	7.644	0.134
Post-test Y8 Test 2	90	7.610	0.118	84	7.657	0.115
Post-test Y8 End of Year Report Grade	89	7.616	0.125	90	7.616	0.121

Table 99 The Science investigation skills assessments pre-test & post-test means and standard deviations for both the control group and the active group

Science Skills Investigation Component Assessed	Control Group			Active Group		
	N	Mean	SD	N	Mean	SD
Pre-test Planning	84	7.311	0.104	81	7.424	0.080
Post-test Y7 Electromagnet Planning	29	7.521	0.094	79	7.465	0.154
Post-test Y7 Yeast Planning	29	7.510	0.135	3	7.567	0.115
Post- test Y8 Planning Reaction Series	29	7.528	0.100	55	7.576	0.160
Post-test Y8 Planning Sound	0			29	7.517	0.123
Pre-test Obtaining Evidence	57	7.365	0.140	80	7.394	0.109
Post-test Y7 Electromagnets Obtaining Evidence	29	7.507	0.088	80	7.515	0.122
Post-test Y7 Rock Salt Obtaining Evidence	30	7.508	0.087	24	7.467	0.109
Post-test Y7 Heart Rate Obtaining Evidence	59	7.524	0.060	29	7.586	0.079
Post-test Y7 Spring Obtaining Evidence	26	7.581	0.094	29	7.517	0.047
Post-test Y7 Yeast Obtaining Evidence	29	7.503	0.132	3	7.667	0.058
Post-test Y8 Pendulum Obtaining Evidence	84	7.560	0.154	81	7.663	0.158
Post-test Y8 Seed dispersal Obtaining Evidence	86	7.578	0.147	52	7.542	0.136
Pre-test Analysis	83	7.381	0.117	86	7.440	0.088
Post-test Y7 Heart Rate Analysis	52	7.429	0.102	28	7.536	0.183
Post-test Y7 Spring Analysis	23	7.430	0.115	19	7.440	0.122
Post-test Y7 Yeast Analysis	29	7.376	0.166	3	7.567	0.115
Post-test Y8 Pendulum Analysis	66	7.466	0.193	77	7.539	0.184
Post-test Y8 Seed dispersal Analysis	82	7.551	0.141	50	7.492	0.148

Post-test Y8 Sound Analysis	0			29	7.535	0.111
Pre-test Evaluating	63	7.337	0.099	76	7.384	0.095
Post-test Y7 Rock Salt Evaluating	27	7.359	0.112	12	7.480	0.122
Post-test Y7 Spring Evaluating	19	7.374	0.128	11	7.370	0.149
Post-test Y7 Salt Evaluating	27	7.456	0.109	0		
Post-test Y7 Yeast Evaluating	26	7.358	0.090	3	7.400	0.173
Post-test Y8 Reaction Series Evaluating	15	7.460	0.091	35	7.474	0.170
Post-test Y8 Rusting Evaluating	0			0		

Table 100 The Science assessments for home work pre-test & post-test means and standard deviations for both the control group and the active group

Science Home Work Component Assessed	Control Group			Active Group		
	N	Mean	SD	N	Mean	SD
Pre-test Physics Assessed Home Work 1a	58	7.447	0.131	54	7.463	0.209
Pre-test Physics Assessed Home Work 1b	53	7.385	0.139	50	7.370	0.161
Pre-test Physics Assessed Home Work 1c	56	7.425	0.144	50	7.398	0.193
Post-test Physics Assessed Home Work 2a	29	7.431	0.154	56	7.493	0.165
Post-test Physics Assessed Home Work 2b	29	7.366	0.137	49	7.357	0.206
Pre-test Chemistry Assessed Home Work 1a	56	7.388	0.128	57	7.418	0.123
Pre-test Chemistry Assessed Home Work 1b	56	7.479	0.170	57	7.581	0.156
Post-test Chemistry Assessed Home Work 2a	29	7.462	0.211	55	7.484	0.242
Post-test Chemistry Assessed Home Work 2b	29	7.524	0.240	58	7.543	0.241
Pre-test Biology Assessed Home Work 1a	57	7.349	0.176	55	7.402	0.217
Pre-test Biology Assessed Home Work 1b	40	7.305	0.154	32	7.450	0.230
Post-test Biology Assessed Home Work 2a	0	NA	NA	25	7.300	0.151
Post-test Biology Assessed Home Work 2b	0	NA	NA	23	7.270	0.136

H: 4.1.4 Comparing the means of the Post-test Science Attainment Assessments independent (unpaired) t-tests

Table 101 The results of an independent (unpaired t-test) on the post-test results of the summative Science attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Post-test Y7 Test 2	7.469	0.095	7.439	0.110	146	1.741	.084
Post-test Y7 Test 3	7.447	0.087	7.416	0.081	141	2.201	.029(p≤.05)
Post-test Y7 End of Year Test	7.435	0.124	7.437	0.113	141	- 0.099	.921
Post-test Y7 End of Year Report grade	7.460	0.120	7.452	0.121	179	0.428	.669
Post-test Y8 Test 1	7.636	0.134	7.644	0.134	174	- 0.426	.671
Post-test Y8 Test 2	7.610	0.118	7.657	0.115	172	- 2.660	.009(p≤.05)
Post-test Y8 End of Year Report Grade	7.616	0.125	7.616	0.121	177	0.040	.968

An independent-samples t-test was conducted to compare the Post-test Year 7 Test 2 Science attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4685, SD=0.09486) and the active group (M=7.4390, SD=0.10989) conditions; t(146)=1.741, p=.084

An independent-samples t-test was conducted to compare the Post-test Year 7 Test 3 Science attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.4472, SD=0.08683) and the active group (M=7.4156, SD=0.0860) conditions; t(141)=2.201, p=.029

An independent-samples t-test was conducted to compare the Post-test Year 7 End of Year Test Science attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4345, SD=0.12362) and the active group (M=7.4345, SD=0.12362) conditions; t(141)=-0.099, p=.921

An independent-samples t-test was conducted to compare the Post-test Year 7 End of Year Report Grade Science attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4599, SD=0.12024) and the active group (M=7.4522, SD=0.12084) conditions; t(179)=0.428, p=.669

An independent-samples t-test was conducted to compare the Post-test Year 8 Test 1 Science attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.6356, SD=0.13434) and the active group (M=7.6442, SD=0.13426) conditions; t(174)=-0.426, p=.671

An independent-samples t-test was conducted to compare the Post-test Year 8 Test 2 Science attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.6100, SD=0.11808) and the active group (M=7.6571, SD=0.11542) conditions; t(172)=-2.660, p=.009

An independent-samples t-test was conducted to compare the Post-test End of Year 8 Report Grade Science attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.6163, SD=0.12518) and the active group (M=7.6156, SD=0.12078) conditions; t(177)=0.040, p=.968

The outcome of the independent t-tests for the post-test Science Summative Assessment attainment comparing the means of the control and active group indicate that WM activities have no significant impact on the Science Summative Assessment attainment. However, the active group had a significantly higher mean in Year 8 Science Test 2, however the control group had a significantly higher mean in the Year 7 Science Test 3. Overall, this indicates that Science attainment may not be improved by students completing WM activities in their Science lessons.

Table 102 The results of an independent (unpaired t-test) on the post-test results of the Science Planning Investigation Skills attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Post-test Y7 Electromagnet Planning	7.521	0.094	7.465	0.154	106	1.833	.070
Post-test Y7 Yeast Planning	7.510	0.135	7.567	0.115	30	-0.696	.492
Post- test Y8 Planning Reaction Series	7.528	0.100	7.576	0.160	82	-1.495	.139
Post-test Y8 Planning Sound	NA	NA	7.517	0.123	NA	NA	NA

An independent-samples t-test was conducted to compare the Electromagnet Planning Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5207, SD=0.09403) and the active group (M=7.4646, SD=0.15445) conditions; t(106)=1.833, p=.070

An independent-samples t-test was conducted to compare the Yeast Planning Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5103, SD=0.13455) and the active group (M=7.5667, SD=0.11547) conditions; t(30)=-0.696, p=.492

An independent-samples t-test was conducted to compare the Reaction Series Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5276, SD=0.09963) and the active group (M=7.5764, SD=0.15982) conditions; t(82)=-1.495, p=.139

The outcome of the independent t-tests for the Science Planning Investigative Skills Assessment attainment comparing the means of the control and active group indicate that WM activities have no significant impact on the Science Planning Investigative Skills Assessment attainment. Overall, this indicates that Science attainment may not be improved by students completing WM activities in their Science lessons.

Table 103 The results of an independent (unpaired t-test) on the post-test results of the Science Obtaining Evidence Investigation Skills attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Post-test Y7 Electromagnets Obtaining Evidence	7.507	0.088	7.515	0.122	107	-0.327	.744
Post-test Y7 Rock Salt Obtaining Evidence	7.507	0.087	7.467	0.109	52	1.502	.139
Post-test Y7 Heart Rate Obtaining Evidence	7.524	0.060	7.586	0.079	86	-4.138	.000($p \leq .001$)
Post-test Y7 Spring Obtaining Evidence	7.581	0.094	7.517	0.047	53	3.226	.002($p \leq .05$)
Post-test Y7 Yeast Obtaining Evidence	7.503	0.132	7.667	0.058	30	-2.092	.045($p \leq .05$)
Post-test Y8 Pendulum Obtaining Evidence	7.560	0.154	7.663	0.158	163	-4.256	.000($p \leq .001$)
Post-test Y8 Seed dispersal Obtaining Evidence	7.578	0.147	7.542	0.136	136	1.419	.158

An independent-samples t-test was conducted to compare the Electromagnets Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5069, SD=0.08836) and the active group (M=7.5150, SD=0.12232) conditions; t(107)=-0.327, p=.744

An independent-samples t-test was conducted to compare the Rock Salt Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5067, SD=0.08683) and the active group (M=7.4667, SD=0.10901) conditions; t(52)=2.502, p=.139

An independent-samples t-test was conducted to compare the Heart Rate Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.5237, SD=0.05971) and the active group (M=7.5862, SD=0.007894) conditions; t(86)=-4.138, p=.000

An independent-samples t-test was conducted to compare the Spring Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.5808, SD=0.09389) and the active group (M=7.5172, SD=0.04682) conditions; t(53)=3.226, p=.002

An independent-samples t-test was conducted to compare the Yeast Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.5034, SD=0.13224) and the active group (M=7.6667, SD=0.05774) conditions; t(30)=-2.092, p=.045

An independent-samples t-test was conducted to compare the Pendulum Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.5595, SD=0.15376) and the active group (M=7.6630, SD=0.15846) conditions; t(163)=-4.256, p=.000

An independent-samples t-test was conducted to compare the Seed Dispersal Obtaining Evidence Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5779, SD=0.14665) and the active group (M=7.5423, SD=0.13626) conditions; t(136)=1.419, p=.158

The outcome of the independent t-tests for the Obtaining Evidence Science Investigative Skills Assessment attainment comparing the means of the control and active group indicate that WM activities may significantly impact on the Obtaining Evidence Science Investigative Skills Assessment attainment. The active group have significantly higher means for the Heart Rate, Yeast and

Pendulum Investigations Obtaining Evidence assessment. On the other hand, the control group have a significantly higher mean for the Spring Investigation Obtaining Evidence assessment. This may suggest that Obtaining Evidence assessment attainment may be improved by students completing WM activities during their Science lessons.

Table 104 The results of an independent (unpaired t-test) on the post-test results of the Science Analysis Investigation Skills attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Post-test Y7 Heart Rate Analysis	7.429	0.102	7.536	0.183	78	-3.366	.001(p≤.001)
Post-test Y7 Spring Analysis	7.430	0.115	7.440	0.122	40	-0.320	.751
Post-test Y7 Yeast Analysis	7.376	0.166	7.567	0.115	30	-1.927	.064
Post-test Y8 Pendulum Analysis	7.465	0.193	7.539	0.184	141	-2.343	.021(p≤.05)
Post-test Y8 Seed dispersal Analysis	7.551	0.141	7.492	0.148	130	2.298	.023(p≤.05)
Post-test Y8 Sound Analysis	NA	NA	7.535	0.111	NA	NA	NA

An independent-samples t-test was conducted to compare the Heart Rate Analysis Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.4288, SD=0.10163) and the active group (M=7.5357, SD=0.18301) conditions; t(78)=-3.366, p=.0.001

An independent-samples t-test was conducted to compare the Spring Analysis Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4304, SD=0.11455) and the active group (M=7.44, SD=0.122) conditions; t(48)=-0.320, p=.751

An independent-samples t-test was conducted to compare the Yeast Analysis Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.3759, SD=0.16617) and the active group (M=7.5667, SD=0.11547) conditions; t(30)=-1.927, p=.064

An independent-samples t-test was conducted to compare the Pendulum Analysis Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.4652, SD=0.19255) and the active group (M=7.5390, SD=0.18364) conditions; t(140)=-2.343, p=.021

An independent-samples t-test was conducted to compare the Seed Dispersal Analysis Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.5512, SD=0.14076) and the active group (M=7.4920, SD=0.14824) conditions; t(130)=2.298, p=.023

The outcome of the independent t-tests for the post-test Analysis Science Investigative Skills Assessment attainment comparing the means of the control and active group indicate that WM activities may have a significant impact on the Analysis Science Investigative Skills Assessment attainment. The active group had a significantly higher means for the analysis assessment of the Heart Rate, Yeast and Pendulum Investigations; however, the control group had a significantly higher mean in the analysis assessment of the Seed Dispersal Investigation. This may suggest that Analysis Science Investigative Skills Assessment attainment may be improved by students completing WM activities during their Science lessons.

Table 105 The results of an independent (unpaired t-test) on the post-test results of the Science Evaluating Investigation Skills attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Post-test Y7 Rock Salt Evaluating	7.359	0.112	7.480	0.122	37	-2.906	.006($p \leq .05$)
Post-test Y7 Spring Evaluating	7.374	0.128	7.370	0.149	28	0.019	.985
Post-test Y7 Salt Evaluating	7.456	0.109	NA	NA	NA	NA	NA
Post-test Y7 Yeast Evaluating	7.358	0.090	7.400	0.173	27	-0.702	.488
Post-test Y8 Reaction Series Evaluating	7.460	0.091	7.474	0.170	48	-0.305	.761
Post-test Y8 Rusting Evaluating	NA	NA	NA	NA	NA	NA	NA

An independent-samples t-test was conducted to compare the Rock Salt Evaluating Science Investigative Skills attainment in the control and active group conditions. There was a significant difference in the scores for control group (M=7.3593, SD=0.11184) and the active group (M=7.48, SD=0.122) conditions; t(37)=-2.906, p=.006

An independent-samples t-test was conducted to compare the Spring Evaluating Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.3737, SD=0.12842) and the active group (M=7.37, SD=0.149) conditions; t(28)=0.019, p=.985

An independent-samples t-test was conducted to compare the Yeast Evaluating Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.3577, SD=0.09021) and the active group (M=7.4000, SD=0.17321) conditions; t(27)=-0.702, p=.488

An independent-samples t-test was conducted to compare the Reaction Series Evaluating Science Investigative Skills attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4600, SD=0.09103) and the active group (M=7.4743, SD=0.17037) conditions; t(48)=-0.305, p=.761

The outcome of the independent t-tests for the Science Evaluating Investigative Skills Assessment attainment comparing the means of the control and active group indicate that WM activities have no significant impact on the Science Evaluating Investigative Skills Assessment attainment. However, the active group have a significantly higher mean for evaluating the Rock Salt Investigation; this is only one of the three evaluating outcomes. Overall, this indicates that Science attainment in Evaluating Investigative Skills assessment may not be improved by students completing WM activities in their Science lessons.

Table 106 The results of an independent (unpaired t-test) on the post-test results of the Science Chemistry Homework attainment assessments comparing the means of the Control and the Active group

Student cohort	Control		Active		df	t	p
Science Attainment Component Assessed	M	SD	M	SD			
Chemistry 2a	7.462	0 .211	7.484	0.242	82	-0.406	.686
Chemistry 2b	7.524	0.240	7.543	0.241	85	-0.346	.730

An independent-samples t-test was conducted to compare the Chemistry a homework attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.4621, SD=0.21114) and the active group (M=7.4836, SD=0.24173) conditions; t(82)=-0.406, p=.686.

An independent-samples t-test was conducted to compare the Chemistry b homework attainment in the control and active group conditions. There was not a significant difference in the scores for control group (M=7.5241, SD=0.24002) and the active group (M=7.5431, SD=0.24142) conditions; t(85)=-0.346, p=.730

The outcome of the independent t-tests for the Science Chemistry Homework Assessment attainment comparing the means of the control and active group indicate that WM activities have no significant impact on the Chemistry Homework Assessment attainment. Overall, this indicates that Science attainment in Chemistry Homework assessment may not be improved by students completing WM activities in their Science lessons.

In summary the independent t-tests of the WM assessment and Science Attainment assessment indicate that there is no significant difference in the vast majority of the means of these measures; hence the outcome suggests that students completing WM activities in Science lessons may have no significant impact on student WM or student Science attainment.

H: 4.2 Correlations between Working Memory Assessments and Science Assessment Attainment in both the control and active condition

H: 4.2.1 Correlations between Pre-test (Baseline) Working Memory Assessments and Science Assessment Attainment in both the control and active conditions

The correlations between the pre-test (baseline) WM assessments and the Science Assessment Attainment for both the control and active conditions were conducted so their outcomes can act as a comparison between the outcomes of the correlations between, the post-test WM assessments and Science Assessment Attainment. In order for the post-test correlations to be significant the pre-test correlations should not be significant or the pre-test r value should be less than that of the post-test correlation r value.

Table 107 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Year 7 Summative Science Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Summative Science Assessment Attainment	Df	r	p	WM assessment measure	Summative Science Assessment Attainment	Df	r	p
Word Recall	Y7 Test 1	51	0.056	.689	Word Recall	Y7 Test 1	77	0.108	.343
Pattern Recall	Y7 Test 1	51	-0.067	.631	Pattern Recall	Y7 Test 1	77	0.274	.015(≤.05)
Counting Recall	Y7 Test 1	51	0.071	.611	Counting Recall	Y7 Test 1	77	0.060	.602
Working Memory Composite	Y7 Test 1	51	0.048	.734	Working Memory Composite	Y7 Test 1	77	0.180	.112
Working Memory Processing	Y7 Test 1	51	-0.035	.805	Working Memory Processing	Y7 Test 1	77	0.158	.167
Word Recall	Y7 Test 2	80	0.435	.000(≤.001)	Word Recall	Y7 Test 2	48	0.395	.005(≤.05)
Pattern Recall	Y7 Test 2	80	0.271	.014(≤.05)	Pattern Recall	Y7 Test 2	48	0.244	.087(≤.05)
Counting Recall	Y7 Test 2	80	0.359	.001(≤.001)	Counting Recall	Y7 Test 2	48	0.194	.176
Working Memory Composite	Y7 Test 2	80	0.459	.000(≤.001)	Working Memory Composite	Y7 Test 2	48	0.351	.012(≤.05)
Working Memory Processing	Y7 Test 2	80	.313	.004(≤.05)	Working Memory Processing	Y7 Test 2	48	0.290	.043(≤.05)
Word Recall	Y7 Test 3	45	0.184	.215	Word Recall	Y7 Test 3	77	0.255	.023(≤.05)
Pattern Recall	Y7 Test 3	45	0.071	.636	Pattern Recall	Y7 Test 3	77	0.290	.009(≤.05)
Counting Recall	Y7 Test 3	45	0.120	.421	Counting Recall	Y7 Test 3	77	0.076	.508

Working Memory Composite	Y7 Test 3	45	0.171	.251	Working Memory Composite	Y7 Test 3	77	0.270	.016(≤.05)
Working Memory Processing	Y7 Test 3	45	0.239	.106	Working Memory Processing	Y7 Test 3	77	0.082	.474
Word Recall	End of Y7 Test	50	0.230	.102	Word Recall	End of Y7 Test	72	0.332	.004(≤.05)
Pattern Recall	End of Y7 Test	50	0.236	.093	Pattern Recall	End of Y7 Test	72	0.268	.021(≤.05)
Counting Recall	End of Y7 Test	50	0.155	.272	Counting Recall	End of Y7 Test	72	0.071	.546
Working Memory Composite	End of Y7 Test	50	0.244	.081	Working Memory Composite	End of Y7 Test	72	0.276	.017(≤.05)
Working Memory Processing	End of Y7 Test	50	0.369	.007(≤.05)	Working Memory Processing	End of Y7 Test	72	0.166	.157
Word Recall	End of Y7 Report Grade	81	0.117	.292	Word Recall	End of Y7 Report Grade	77	0.176	.121
Pattern Recall	End of Y7 Report Grade	81	0.126	.254	Pattern Recall	End of Y7 Report Grade	77	0.267	.017(≤.05)
Counting Recall	End of Y7 Report Grade	81	0.162	.142	Counting Recall	End of Y7 Report Grade	77	0.085	.458
Working Memory Composite	End of Y7 Report Grade	81	0.178	.108	Working Memory Composite	End of Y7 Report Grade	77	0.218	.054
Working Memory Processing	End of Y7 Report Grade	81	0.186	.092	Working Memory Processing	End of Y7 Report Grade	77	0.207	.069

Table 108 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Year 8 Summative Science Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Summative Science Assessment Attainment	Df	r	p	WM assessment measure	Summative Science Assessment Attainment	Df	r	p
Word Recall	Y8 Test 1	80	0.341	.002(≤.05)	Word Recall	Y8 Test 1	72	0.079	.503
Pattern Recall	Y8 Test 1	80	0.019	.867	Pattern Recall	Y8 Test 1	72	0.157	.182
Counting Recall	Y8 Test 1	80	0.213	.055	Counting Recall	Y8 Test 1	72	0.094	.428
Working Memory Composite	Y8 Test 1	80	0.277	.012(≤.05)	Working Memory Composite	Y8 Test 1	72	0.143	.223
Working Memory Processing	Y8 Test 1	80	0.086	.443	Working Memory Processing	Y8 Test 1	72	0.100	.399
Word Recall	Y8 Test 2	80	0.262	.017(≤.05)	Word Recall	Y8 Test 2	71	0.025	.834
Pattern Recall	Y8 Test 2	80	0.049	.659	Pattern Recall	Y8 Test 2	71	0.162	.171
Counting Recall	Y8 Test 2	80	-.008	.945	Counting Recall	Y8 Test 2	71	0.159	.180
Working Memory Composite	Y8 Test 2	80	0.120	.285	Working Memory Composite	Y8 Test 2	71	0.171	.149
Working Memory Processing	Y8 Test 2	80	0.161	.148	Working Memory Processing	Y8 Test 2	71	.053	.657

Word Recall	End of Y8 Report Grade	79	0.420	.000(≤.001)	Word Recall	End of Y8 Report Grade	75	0.235	.040(≤.05)
Pattern Recall	End of Y8 Report Grade	79	0.125	.268	Pattern Recall	End of Y8 Report Grade	75	-0.078	.503
Counting Recall	End of Y8 Report Grade	79	0.329	.003(≤.05)	Counting Recall	End of Y8 Report Grade	75	0.105	.364
Working Memory Composite	End of Y8 Report Grade	79	0.403	.000(≤.001)	Working Memory Composite	End of Y8 Report Grade	75	0.141	.223
Working Memory Processing	End of Y8 Report Grade	79	0.178	.113	Working Memory Processing	End of Y8 Report Grade	75	0.098	.398

Table 109 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Planning Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline Planning	76	0.096	.401	Word Recall	Baseline Planning	73	0.007	.953
Pattern Recall	Baseline Planning	76	0.090	.433	Pattern Recall	Baseline Planning	73	0.186	.109
Counting Recall	Baseline Planning	76	0.189	.098	Counting Recall	Baseline Planning	73	0.104	.373
Working Memory Composite	Baseline Planning	76	0.172	.131	Working Memory Composite	Baseline Planning	73	0.144	.218

Working Memory Processing	Baseline Planning	76	0.142	.215	Working Memory Processing	Baseline Planning	73	0.025	.831
Word Recall	Electromagnet Planning	26	0.052	.791	Word Recall	Electromagnet Planning	70	0.268	.023
Pattern Recall	Electromagnet Planning	26	0.185	.346	Pattern Recall	Electromagnet Planning	70	0.232	.05(≤.05)
Counting Recall	Electromagnet Planning	26	0.172	.383	Counting Recall	Electromagnet Planning	70	0.180	.131
Working Memory Composite	Electromagnet Planning	26	0.164	.405	Working Memory Composite	Electromagnet Planning	70	0.305	.009(≤.05)
Working Memory Processing	Electromagnet Planning	26	-0.268	.168	Working Memory Processing	Electromagnet Planning	70	0.256	.031(≤.05)
Word Recall	Yeast Planning	27	0.364	.053	Word Recall	Yeast Planning	1	-0.072	.954
Pattern Recall	Yeast Planning	27	0.363	.053	Pattern Recall	Yeast Planning	1	0.629	.567
Counting Recall	Yeast Planning	27	0.217	.259	Counting Recall	Yeast Planning	1	0.629	.567
Working Memory Composite	Yeast Planning	27	0.409	.028(≤.05)	Working Memory Composite	Yeast Planning	1	0.768	.443
Working Memory Processing	Yeast Planning	27	0.271	.156	Working Memory Processing	Yeast Planning	1	0.991	.084
Word Recall	Reaction Series Planning	27	-0.05	.798	Word Recall	Reaction Series Planning	45	0.034	.819

Pattern Recall	Reaction Series Planning	27	0.218	.255	Pattern Recall	Reaction Series Planning	45	0.160	.283
Counting Recall	Reaction Series Planning	27	0.141	.466	Counting Recall	Reaction Series Planning	45	0.090	.546
Working Memory Composite	Reaction Series Planning	27	0.168	.385	Working Memory Composite	Reaction Series Planning	45	0.164	.270
Working Memory Processing	Reaction Series Planning	27	0.304	.108	Working Memory Processing	Reaction Series Planning	45	0.112	.458
Word Recall	Sound Planning	No data	No data	No data	Word Recall	Sound Planning	21	0.199	.362
Pattern Recall	Sound Planning	No data	No data	No data	Pattern Recall	Sound Planning	21	0.159	.469
Counting Recall	Sound Planning	No data	No data	No data	Counting Recall	Sound Planning	21	0.191	.383
Working Memory Composite	Sound Planning	No data	No data	No data	Working Memory Composite	Sound Planning	21	0.242	.266
Working Memory Processing	Sound Planning	No data	No data	No data	Working Memory Processing	Sound Planning	21	0.067	.767

Table 110 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Obtaining Evidence Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills	Df	r	p	WM assessment measure	Science Investigative Skills	Df	r	p

	Assessment Attainment					Assessment Attainment			
Word Recall	Baseline Obtaining Evidence	50	0.157	.266	Word Recall	Baseline Obtaining Evidence	72	-0.022	.851
Pattern Recall	Baseline Obtaining Evidence	50	0.062	.660	Pattern Recall	Baseline Obtaining Evidence	72	0.156	.183
Counting Recall	Baseline Obtaining Evidence	50	0.196	.163	Counting Recall	Baseline Obtaining Evidence	72	-0.003	.978
Working Memory Composite	Baseline Obtaining Evidence	50	0.186	.188	Working Memory Composite	Baseline Obtaining Evidence	72	0.041	.727
Working Memory Processing	Baseline Obtaining Evidence	50	0.125	.379	Working Memory Processing	Baseline Obtaining Evidence	72	-0.112	.346
Word Recall	Electromagnets Obtaining Evidence	26	- 0.049	.804	Word Recall	Electromagnets Obtaining Evidence	71	0.052	.664
Pattern Recall	Electromagnets Obtaining Evidence	26	- 0.024	.902	Pattern Recall	Electromagnets Obtaining Evidence	71	0.152	.200
Counting Recall	Electromagnets Obtaining Evidence	26	0.081	.683	Counting Recall	Electromagnets Obtaining Evidence	71	0.023	.848
Working Memory Composite	Electromagnets Obtaining Evidence	26	0.032	.870	Working Memory Composite	Electromagnets Obtaining Evidence	71	0.078	.513
Working Memory Processing	Electromagnets Obtaining Evidence	26	0.028	.891	Working Memory Processing	Electromagnets Obtaining Evidence	71	0.045	.709
Word Recall	Rock Salt Obtaining Evidence	27	- 0.049	.800	Word Recall	Rock Salt Obtaining Evidence	25	-0.088	.684

Pattern Recall	Rock Salt Obtaining Evidence	27	-0.025	.899	Pattern Recall	Rock Salt Obtaining Evidence	25	-0.485	.016
Counting Recall	Rock Salt Obtaining Evidence	27	0.081	.676	Counting Recall	Rock Salt Obtaining Evidence	25	-0.238	.262
Working Memory Composite	Rock Salt Obtaining Evidence	27	0.032	.867	Working Memory Composite	Rock Salt Obtaining Evidence	25	-0.363	.082
Working Memory Processing	Rock Salt Obtaining Evidence	27	0.027	.891	Working Memory Processing	Rock Salt Obtaining Evidence	25	-0.104	.628
Word Recall	Heart Rate Obtaining Evidence	50	-.0269	.053	Word Recall	Heart Rate Obtaining Evidence	24	0.110	.586
Pattern Recall	Heart Rate Obtaining Evidence	50	-0.319	.021(≤.05)	Pattern Recall	Heart Rate Obtaining Evidence	24	0.087	.666
Counting Recall	Heart Rate Obtaining Evidence	50	-0.268	.055	Counting Recall	Heart Rate Obtaining Evidence	24	0.170	.397
Working Memory Composite	Heart Rate Obtaining Evidence	50	-0.344	.013(≤.05)	Working Memory Composite	Heart Rate Obtaining Evidence	24	0.197	.325
Working Memory Processing	Heart Rate Obtaining Evidence	50	-0.133	.347	Working Memory Processing	Heart Rate Obtaining Evidence	24	0.255	.199
Word Recall	Spring Obtaining Evidence	18	0.300	.198	Word Recall	Spring Obtaining Evidence	1	0.146	.477
Pattern Recall	Spring Obtaining Evidence	18	0.078	.743	Pattern Recall	Spring Obtaining Evidence	1	-0.015	.943

Counting Recall	Spring Obtaining Evidence	18	0.237	.314	Counting Recall	Spring Obtaining Evidence	1	-0.109	.595
Working Memory Composite	Spring Obtaining Evidence	18	0.260	.268	Working Memory Composite	Spring Obtaining Evidence	1	-0.021	.917
Working Memory Processing	Spring Obtaining Evidence	18	0.194	.412	Working Memory Processing	Spring Obtaining Evidence	1	0.024	.907
Word Recall	Yeast Obtaining Evidence	27	0.258	.177	Word Recall	Yeast Obtaining Evidence	68	-0.900	.287
Pattern Recall	Yeast Obtaining Evidence	27	0.649	.000(≤.001)	Pattern Recall	Yeast Obtaining Evidence	68	0.988	.099
Counting Recall	Yeast Obtaining Evidence	27	0.355	.059	Counting Recall	Yeast Obtaining Evidence	68	0.988	.099
Working Memory Composite	Yeast Obtaining Evidence	27	0.573	.001(≤.001)	Working Memory Composite	Yeast Obtaining Evidence	68	0.939	.224
Working Memory Processing	Yeast Obtaining Evidence	27	0.555	.002(≤.05)	Working Memory Processing	Yeast Obtaining Evidence	68	0.381	.751
Word Recall	Pendulum Obtaining Evidence	75	0.321	.004(≤.05)	Word Recall	Pendulum Obtaining Evidence	43	0.077	.526
Pattern Recall	Pendulum Obtaining Evidence	75	0.110	.340	Pattern Recall	Pendulum Obtaining Evidence	43	-0.177	.142
Counting Recall	Pendulum Obtaining Evidence	75	0.277	.015(≤.05)	Counting Recall	Pendulum Obtaining Evidence	43	.097	.427
Working Memory Composite	Pendulum Obtaining Evidence	75	0.324	.004(≤.05)	Working Memory Composite	Pendulum Obtaining Evidence	43	0.039	.748

Working Memory Processing	Pendulum Obtaining Evidence	75	0.214	.062	Working Memory Processing	Pendulum Obtaining Evidence	43	0.053	.041(≤.05)
Word Recall	Y8 Seed dispersal Obtaining Evidence	77	0.127	.266	Word Recall	Y8 Seed dispersal Obtaining Evidence	43	0.123	.420
Pattern Recall	Y8 Seed dispersal Obtaining Evidence	77	0.116	.307	Pattern Recall	Y8 Seed dispersal Obtaining Evidence	43	0.059	.702
Counting Recall	Y8 Seed dispersal Obtaining Evidence	77	0.074	.516	Counting Recall	Y8 Seed dispersal Obtaining Evidence	43	0.323	.031(≤.05)
Working Memory Composite	Y8 Seed dispersal Obtaining Evidence	77	0.117	.306	Working Memory Composite	Y8 Seed dispersal Obtaining Evidence	43	0.286	.057
Working Memory Processing	Y8 Seed dispersal Obtaining Evidence	77	0.248	.028(≤.05)	Working Memory Processing	Y8 Seed dispersal Obtaining Evidence	43	0.041	.790

Table 111 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Analysis Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline analysis	75	0.305	.007(≤.05)	Word Recall	Baseline analysis	76	0.230	.043(≤.05)
Pattern Recall	Baseline analysis	75	0.077	.508	Pattern Recall	Baseline analysis	76	0.087	.450

Counting Recall	Baseline analysis	75	0.116	.317	Counting Recall	Baseline analysis	76	0.072	.529
Working Memory Composite	Baseline analysis	75	0.213	.063	Working Memory Composite	Baseline analysis	76	0.167	.144
Working Memory Processing	Baseline analysis	75	0.165	.152	Working Memory Processing	Baseline analysis	76	0.135	.242
Word Recall	Heart Rate Analysis	43	-0.219	.149	Word Recall	Heart Rate Analysis	25	-0.023	.908
Pattern Recall	Heart Rate Analysis	43	-0.131	.389	Pattern Recall	Heart Rate Analysis	25	0.052	.797.
Counting Recall	Heart Rate Analysis	43	-0.091	.552	Counting Recall	Heart Rate Analysis	25	0.008	.970
Working Memory Composite	Heart Rate Analysis	43	-0.181	.233	Working Memory Composite	Heart Rate Analysis	25	0.019	.927
Working Memory Processing	Heart Rate Analysis	43	-0.030	.845	Working Memory Processing	Heart Rate Analysis	25	-0.109	.587
Word Recall	Spring Analysis	15	0.248	.336	Word Recall	Spring Analysis	16	0.080	.751
Pattern Recall	Spring Analysis	15	0.176	.499	Pattern Recall	Spring Analysis	16	0.258	.301
Counting Recall	Spring Analysis	15	0.145	.579	Counting Recall	Spring Analysis	16	0.077	.761
Working Memory Composite	Spring Analysis	15	0.193	.457	Working Memory Composite	Spring Analysis	16	0.154	.542
Working Memory Processing	Spring Analysis	15	0.354	.164	Working Memory Processing	Spring Analysis	16	0.202	.421
Word Recall	Yeast Analysis	27	0.214	.265	Word Recall	Yeast Analysis	1	-0.828	.379
Pattern Recall	Yeast Analysis	27	-0.012	.953	Pattern Recall	Yeast Analysis	1	0.359	.766

Counting Recall	Yeast Analysis	27	0.177	.359	Counting Recall	Yeast Analysis	1	0.359	.766
Working Memory Composite	Yeast Analysis	27	0.173	.371	Working Memory Composite	Yeast Analysis	1	0.171	.891
Working Memory Processing	Yeast Analysis	27	0.285	.135	Working Memory Processing	Yeast Analysis	1	-0.610	.582
Word Recall	Pendulum Analysis	60	0.030	.820	Word Recall	Pendulum Analysis	64	0.121	.332
Pattern Recall	Pendulum Analysis	60	0.037	.775	Pattern Recall	Pendulum Analysis	64	-0.054	.669
Counting Recall	Pendulum Analysis	60	0.181	.159	Counting Recall	Pendulum Analysis	64	0.017	.891
Working Memory Composite	Pendulum Analysis	60	0.135	.294	Working Memory Composite	Pendulum Analysis	64	0.051	.684
Working Memory Processing	Pendulum Analysis	60	0.077	.554	Working Memory Processing	Pendulum Analysis	64	0.139	.270
Word Recall	Seed dispersal Analysis	73	0.088	.451	Word Recall	Seed dispersal Analysis	41	0.293	.057
Pattern Recall	Seed dispersal Analysis	73	0.049	.676	Pattern Recall	Seed dispersal Analysis	41	0.079	.616
Counting Recall	Seed dispersal Analysis	73	-0.032	.788	Counting Recall	Seed dispersal Analysis	41	0.015	.925
Working Memory Composite	Seed dispersal Analysis	73	0.028	.813	Working Memory Composite	Seed dispersal Analysis	41	0.202	.193
Working Memory Processing	Seed dispersal Analysis	73	0.262	0.028(≤.05)	Working Memory Processing	Seed dispersal Analysis	41	-0.095	.549

Word Recall	Sound Analysis	No data	No data	No data	Word Recall	Sound Analysis	21	0.321	.135
Pattern Recall	Sound Analysis	No data	No data	No data	Pattern Recall	Sound Analysis	21	0.105	.634
Counting Recall	Sound Analysis	No data	No data	No data	Counting Recall	Sound Analysis	21	0.462	.026
Working Memory Composite	Sound Analysis	No data	No data	No data	Working Memory Composite	Sound Analysis	21	0.439	.036
Working Memory Processing	Sound Analysis	No data	No data	No data	Working Memory Processing	Sound Analysis	21	0.249	.264

Table 112 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Evaluating Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline Evaluating	55	0.234	.080	Word Recall	Baseline Evaluating	68	0.142	.240
Pattern Recall	Baseline Evaluating	55	0.193	.151	Pattern Recall	Baseline Evaluating	68	0.004	.973
Counting Recall	Baseline Evaluating	55	0.12	.375	Counting Recall	Baseline Evaluating	68	-0.061	.616

Working Memory Composite	Baseline Evaluating	55	0.215	.108	Working Memory Composite	Baseline Evaluating	68	0.017	.891
Working Memory Processing	Baseline Evaluating	55	0.139	.303	Working Memory Processing	Baseline Evaluating	68	0.022	.855
Word Recall	Rock Salt Evaluating	24	-0.206	.312	Word Recall	Rock Salt Evaluating	10	0.258	.419
Pattern Recall	Rock Salt Evaluating	24	-0.034	.867	Pattern Recall	Rock Salt Evaluating	10	0.514	.088
Counting Recall	Rock Salt Evaluating	24	0.297	.141	Counting Recall	Rock Salt Evaluating	10	0.383	.219
Working Memory Composite	Rock Salt Evaluating	24	0.087	.674	Working Memory Composite	Rock Salt Evaluating	10	0.449	.143
Working Memory Processing	Rock Salt Evaluating	24	-0.113	.583	Working Memory Processing	Rock Salt Evaluating	10	-0.058	.857
Word Recall	Spring Evaluating	12	0.269	.352	Word Recall	Spring Evaluating	9	-0.217	.521
Pattern Recall	Spring Evaluating	12	-0.255	.379	Pattern Recall	Spring Evaluating	9	0.387	.240
Counting Recall	Spring Evaluating	12	0.047	.873	Counting Recall	Spring Evaluating	9	0.433	.184
Working Memory Composite	Spring Evaluating	12	0.071	.810	Working Memory Composite	Spring Evaluating	9	0.394	.231
Working Memory Processing	Spring Evaluating	12	0.253	.383	Working Memory Processing	Spring Evaluating	9	-0.330	.322
Word Recall	Salt Evaluating	24	-0.206	.312	Word Recall	Salt Evaluating	No data	No data	No data

Pattern Recall	Salt Evaluating	24	-0.034	.867	Pattern Recall	Salt Evaluating	No data	No data	No data
Counting Recall	Salt Evaluating	24	0.297	.141	Counting Recall	Salt Evaluating	No data	No data	No data
Working Memory Composite	Salt Evaluating	24	0.087	.674	Working Memory Composite	Salt Evaluating	No data	No data	No data
Working Memory Processing	Salt Evaluating	24	-0.113	.583	Working Memory Processing	Salt Evaluating	No data	No data	No data
Word Recall	Yeast Evaluating	24	0.452	.021(≤.05)	Word Recall	Yeast Evaluating	1	-0.828	.379
Pattern Recall	Yeast Evaluating	24	0.284	.160	Pattern Recall	Yeast Evaluating	1	0.359	.766
Counting Recall	Yeast Evaluating	24	0.127	.538	Counting Recall	Yeast Evaluating	1	0.359	.766
Working Memory Composite	Yeast Evaluating	24	0.327	.103	Working Memory Composite	Yeast Evaluating	1	0.171	.891
Working Memory Processing	Yeast Evaluating	24	.564	.003(≤.05)	Working Memory Processing	Yeast Evaluating	1	-0.610	.582
Word Recall	Reaction Series Evaluating	13	0.291	.292	Word Recall	Reaction Series Evaluating	27	-0.022	.908
Pattern Recall	Reaction Series Evaluating	13	0.515	.05(≤.05)	Pattern Recall	Reaction Series Evaluating	27	-0.043	.824
Counting Recall	Reaction Series Evaluating	13	0.044	.877	Counting Recall	Reaction Series Evaluating	27	0.328	.082
Working Memory Composite	Reaction Series Evaluating	13	0.374	.170	Working Memory Composite	Reaction Series Evaluating	27	0.201	.296
Working Memory Processing	Reaction Series Evaluating	13	0.167	.551	Working Memory Processing	Reaction Series Evaluating	27	-0.007	.971

Word Recall	Rusting Evaluating			No data	Word Recall	Rusting Evaluating		No data	
Pattern Recall	Rusting Evaluating			No data	Pattern Recall	Rusting Evaluating		No data	
Counting Recall	Rusting Evaluating			No data	Counting Recall	Rusting Evaluating		No data	
Working Memory Composite	Rusting Evaluating			No data	Working Memory Composite	Rusting Evaluating		No data	
Working Memory Processing	Rusting Evaluating			No data	Working Memory Processing	Rusting Evaluating		No data	

Table 113 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Physics Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Physics 1a	50	0.247	.077	Word Recall	Physics 1a	46	0.343	.017(≤.05)
Pattern Recall	Physics 1a	50	0.237	.090	Pattern Recall	Physics 1a	46	0.041	.783
Counting Recall	Physics 1a	50	0.156	.271	Counting Recall	Physics 1a	46	0.115	.437
Working Memory Composite	Physics 1a	50	0.233	.097	Working Memory Composite	Physics 1a	46	0.199	.175
Working Memory Processing	Physics 1a	50	0.151	.286	Working Memory Processing	Physics 1a	46	0.242	.101
Word Recall	Physics 1b	45	0.259	.079	Word Recall	Physics 1b	42	0.261	.087

Pattern Recall	Physics 1b	45	0.209	.159	Pattern Recall	Physics 1b	42	0.277	.138
Counting Recall	Physics 1b	45	0.323	.027(≤.05)	Counting Recall	Physics 1b	42	0.153	.323
Working Memory Composite	Physics 1b	45	0.335	.021(≤.05)	Working Memory Composite	Physics 1b	42	0.260	.088
Working Memory Processing	Physics 1b	45	0.144	.333	Working Memory Processing	Physics 1b	42	0.144	.358
Word Recall	Physics 1c	48	0.278	.051	Word Recall	Physics 1c	42	0.141	.361
Pattern Recall	Physics 1c	48	0.240	.093	Pattern Recall	Physics 1c	42	0.263	.085
Counting Recall	Physics 1c	48	0.228	0.111	Counting Recall	Physics 1c	42	0.168	.276
Working Memory Composite	Physics 1c	48	0.299	.035(≤.05)	Working Memory Composite	Physics 1c	42	0.251	.100
Working Memory Processing	Physics 1c	48	0.135	0.350(≤.05)	Working Memory Processing	Physics 1c	42	0.344	.024(≤.05)
Word Recall	Physics 2d	21	0.295	.172	Word Recall	Physics 2d	46	0.120	.415
Pattern Recall	Physics 2d	21	0.205	.348	Pattern Recall	Physics 2d	46	0.069	.639
Counting Recall	Physics 2d	21	0.218	.317	Counting Recall	Physics 2d	46	0.137	.353
Working Memory Composite	Physics 2d	21	0.271	.211	Working Memory Composite	Physics 2d	46	0.157	.287
Working Memory Processing	Physics 2d	21	0.540	.008(≤.05)	Working Memory Processing	Physics 2d	46	0.204	.169
Word Recall	Physics 2e	21	0.214	.327	Word Recall	Physics 2e	39	0.032	.842
Pattern Recall	Physics 2e	21	0.104	.636	Pattern Recall	Physics 2e	39	0.129	.422
Counting Recall	Physics 2e	21	0.180	.410	Counting Recall	Physics 2e	39	0.191	.232

Working Memory Composite	Physics 2e	21	0.196	.371	Working Memory Composite	Physics 2e	39	0.191	.231
Working Memory Processing	Physics 2e	21	0.496	0.016(≤.05)	Working Memory Processing	Physics 2e	39	0.397	.011(≤.05)

Table 114 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Chemistry Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Chemistry 1a	49	0.115	.420	Word Recall	Chemistry 1a	49	0.200	.159
Pattern Recall	Chemistry 1a	49	0.198	.165	Pattern Recall	Chemistry 1a	49	0.030	.833
Counting Recall	Chemistry 1a	49	-0.070	.623	Counting Recall	Chemistry 1a	49	0.114	.425
Working Memory Composite	Chemistry 1a	49	0.047	.743	Working Memory Composite	Chemistry 1a	49	0.169	.236
Working Memory Processing	Chemistry 1a	49	0.066	.648	Working Memory Processing	Chemistry 1a	49	0.300	.034
Word Recall	Chemistry 1b	49	0.280	.046(≤.05)	Word Recall	Chemistry 1b	49	.379	.006(≤.05)
Pattern Recall	Chemistry 1b	49	0.308	.028(≤.05)	Pattern Recall	Chemistry 1b	49	0.066	.646
Counting Recall	Chemistry 1b	49	0.106	.461	Counting Recall	Chemistry 1b	49	0.210	.138
Working Memory Composite	Chemistry 1b	49	0.243	.086	Working Memory Composite	Chemistry 1b	49	0.325	.020(≤.05)
Working Memory Processing	Chemistry 1b	49	0.230	.105	Working Memory Processing	Chemistry 1b	49	0.282	.048(≤.05)
Word Recall	Chemistry 2a	22	0.142	.507	Word Recall	Chemistry 2a	44	0.025	.868
Pattern Recall	Chemistry 2a	22	0.316	.132	Pattern Recall	Chemistry 2a	44	-0.032	.835
Counting Recall	Chemistry 2a	22	0.327	.118	Counting Recall	Chemistry 2a	44	0.071	.641

Working Memory Composite	Chemistry 2a	22	0.287	.174	Working Memory Composite	Chemistry 2a	44	0.044	.772
Working Memory Processing	Chemistry 2a	22	0.457	.025(≤.05)	Working Memory Processing	Chemistry 2a	44	0.097	.528
Word Recall	Chemistry 2b	22	0.099	.644	Word Recall	Chemistry 2b	47	0.173	.235
Pattern Recall	Chemistry 2b	22	0.190	.373	Pattern Recall	Chemistry 2b	47	0.159	.275
Counting Recall	Chemistry 2b	22	0.196	.358	Counting Recall	Chemistry 2b	47	0.124	.394
Working Memory Composite	Chemistry 2b	22	0.170	.428	Working Memory Composite	Chemistry 2b	47	0.216	.137
Working Memory Processing	Chemistry 2b	22	0.398	0.054	Working Memory Processing	Chemistry 2b	47	0.166	.258

Table 115 The outcomes of correlation coefficient tests between Pre-test WM assessment measures and Biology Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Biology 1a	49	-0.063	.659	Word Recall	Biology 1a	44	0.236	.114
Pattern Recall	Biology 1a	49	0.074	.604	Pattern Recall	Biology 1a	44	0.029	.847
Counting Recall	Biology 1a	49	-0.027	.852	Counting Recall	Biology 1a	44	-0.036	.810
Working Memory Composite	Biology 1a	49	-0.025	.862	Working Memory Composite	Biology 1a	44	0.057	.706

Working Memory Processing	Biology 1a	49	0.088	.539	Working Memory Processing	Biology 1a	44	0.253	.094
Word Recall	Biology 1b	33	- 0.0130	.457	Word Recall	Biology 1b	25	0.377	.053
Pattern Recall	Biology 1b	33	-0.045	.796	Pattern Recall	Biology 1b	25	-0.180	.369
Counting Recall	Biology 1b	33	-0.132	.448	Counting Recall	Biology 1b	25	-0.063	.754
Working Memory Composite	Biology 1b	33	-0.136	.435	Working Memory Composite	Biology 1b	25	0.012	.954
Working Memory Processing	Biology 1b	33	-0.002	.990	Working Memory Processing	Biology 1b	25	0.176	.379
Word Recall	Biology 2c	No data	No data	No data	Word Recall	Biology 2c	20	0.195	.384
Pattern Recall	Biology 2c	No data	No data	No data	Pattern Recall	Biology 2c	20	0.220	.325
Counting Recall	Biology 2c	No data	No data	No data	Counting Recall	Biology 2c	20	0.147	.514
Working Memory Composite	Biology 2c	No data	No data	No data	Working Memory Composite	Biology 2c	20	0.228	.307
Working Memory Processing	Biology 2c	No data	No data	No data	Working Memory Processing	Biology 2c	20	0.513	.015(≤.05)
Word Recall	Biology 2d	No data	No data	No data	Word Recall	Biology 2d	18	0.108	.651
Pattern Recall	Biology 2d	No data	No data	No data	Pattern Recall	Biology 2d	18	0.043	.857
Counting Recall	Biology 2d	No data	No data	No data	Counting Recall	Biology 2d	18	-0.043	.858

Working Memory Composite	Biology 2d	No data	No data	No data	Working Memory Composite	Biology 2d	18	0.017	.943
Working Memory Processing	Biology 2d	No data	No data	No data	Working Memory Processing	Biology 2d	18	0.371	0.107

Overall, when analysing the pre-test WM correlation with the science assessments there are no patterns. The pre-test WM assessments are not correlated with summative science assessments, investigative skills assessments or science homework assessments.

H: 4.2.2 Correlations between Post-test Working Memory Assessments and Science Assessment Attainment in both the control and active conditions

Table 116 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Planning Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline Planning	74	0.210	.067	Word Recall	Baseline Planning	74	0.349	.002(≤.05)
Pattern Recall	Baseline Planning	74	0.257	.024(≤.05)	Pattern Recall	Baseline Planning	74	-0.141	.223
Counting Recall	Baseline Planning	74	0.004	.975	Counting Recall	Baseline Planning	74	0.052	.657
Working Memory Composite	Baseline Planning	74	0.148	.198	Working Memory Composite	Baseline Planning	74	0.172	.137

Working Memory Processing	Baseline Planning	74	-0.045	.702	Working Memory Processing	Baseline Planning	74	0.189	.101
Word Recall	Electromagnet Planning	72	0.222	.257	Word Recall	Electromagnet Planning	72	0.232	.046(≤.05)
Pattern Recall	Electromagnet Planning	72	0.029	.884	Pattern Recall	Electromagnet Planning	72	0.130	.271
Counting Recall	Electromagnet Planning	72	-0.021	.914	Counting Recall	Electromagnet Planning	72	0.319	.006(≤.05)
Working Memory Composite	Electromagnet Planning	72	0.087	.661	Working Memory Composite	Electromagnet Planning	72	0.351	.002(≤.05)
Working Memory Processing	Electromagnet Planning	72	0.063	.750	Working Memory Processing	Electromagnet Planning	72	0.014	.904
Word Recall	Yeast Planning	1	0.351	.067	Word Recall	Yeast Planning	1	-0.945	.212
Pattern Recall	Yeast Planning	1	0.447	.017(≤.05)	Pattern Recall	Yeast Planning	1	0.459	.696
Counting Recall	Yeast Planning	1	0.362	.058	Counting Recall	Yeast Planning	1	-0.292	.811
Working Memory Composite	Yeast Planning	1	0.503	.006(≤.05)	Working Memory Composite	Yeast Planning	1	-0.132	.916
Working Memory Processing	Yeast Planning	1	-0.143	.468	Working Memory Processing	Yeast Planning	1	-0.822	.386
Word Recall	Reaction Series Planning	49	0.284	.144	Word Recall	Reaction Series Planning	49	-0.043	.766
Pattern Recall	Reaction Series Planning	49	0.421	.026(≤.05)	Pattern Recall	Reaction Series Planning	49	-0.065	.652
Counting Recall	Reaction Series Planning	49	0.282	.145	Counting Recall	Reaction Series Planning	49	-0.091	.525

Working Memory Composite	Reaction Series Planning	49	0.390	.040(≤.05)	Working Memory Composite	Reaction Series Planning	49	-0.096	.504
Working Memory Processing	Reaction Series Planning	49	0.181	.356	Working Memory Processing	Reaction Series Planning	49	0.087	.549
Word Recall	Sound Planning	No data	No data	No data	Word Recall	Sound Planning	25	0.324	.099
Pattern Recall	Sound Planning	No data	No data	No data	Pattern Recall	Sound Planning	25	0.056	.780
Counting Recall	Sound Planning	No data	No data	No data	Counting Recall	Sound Planning	25	0.126	.531
Working Memory Composite	Sound Planning	No data	No data	No data	Working Memory Composite	Sound Planning	25	0.213	.286
Working Memory Processing	Sound Planning	No data	No data	No data	Working Memory Processing	Sound Planning	25	0.135	.510

The majority of the WM assessments to Investigative Planning Skills Science Assessment Attainment were found not to be correlated for the active group (see Table 38). For example, WM word recall and Reaction Series Planning were not correlated r(49)=-.043, p=.766 and WM Processing Speed and Sound Planning were not correlated r(25)=.135, p=0.510. However, some significant correlations were identified between WM assessment and Electromagnet Planning for example Word Recall and Electromagnet Planning were correlated r(72)=.232, p=046(P≤.05) and WM composite and Electromagnet Planning were correlated r(72)=.351, p=.002 (P≤.05). Three of the five WM assessments were correlated to Planning Electromagnet attainment. This suggests that the WM activities may improve Electromagnet Planning attainment.

Table 117 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Obtaining Evidence Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline Obtaining Evidence	49	0.157	.270	Word Recall	Baseline Obtaining Evidence	73	0.192	.100
Pattern Recall	Baseline Obtaining Evidence	49	0.118	.408	Pattern Recall	Baseline Obtaining Evidence	73	-0.182	.119
Counting Recall	Baseline Obtaining Evidence	49	-0.035	.807	Counting Recall	Baseline Obtaining Evidence	73	-0.137	.242
Working Memory Composite	Baseline Obtaining Evidence	49	0.072	.617	Working Memory Composite	Baseline Obtaining Evidence	73	-.061	.605
Working Memory Processing	Baseline Obtaining Evidence	49	0.245	.086	Working Memory Processing	Baseline Obtaining Evidence	73	-0.150	.200
Word Recall	Electromagnets Obtaining Evidence	26	0.125	.525	Word Recall	Electromagnets Obtaining Evidence	73	0.110	.346
Pattern Recall	Electromagnets Obtaining Evidence	26	-0.261	.179	Pattern Recall	Electromagnets Obtaining Evidence	73	-0.023	.847
Counting Recall	Electromagnets Obtaining Evidence	26	-0.113	.568	Counting Recall	Electromagnets Obtaining Evidence	73	0.156	.182

Working Memory Composite	Electromagnets Obtaining Evidence	26	-0.070	.722	Working Memory Composite	Electromagnets Obtaining Evidence	73	0.135	.247
Working Memory Processing	Electromagnets Obtaining Evidence	26	0.082	.680	Working Memory Processing	Electromagnets Obtaining Evidence	73	0.173	.140
Word Recall	Rock Salt Obtaining Evidence	27	0.124	.523	Word Recall	Rock Salt Obtaining Evidence	21	0.250	.250
Pattern Recall	Rock Salt Obtaining Evidence	27	-0.259	.174	Pattern Recall	Rock Salt Obtaining Evidence	21	-0.474	.022(≤.05)
Counting Recall	Rock Salt Obtaining Evidence	27	-0.107	.581	Counting Recall	Rock Salt Obtaining Evidence	21	-0.285	.187
Working Memory Composite	Rock Salt Obtaining Evidence	27	-0.068	.724	Working Memory Composite	Rock Salt Obtaining Evidence	21	-0.246	.258
Working Memory Processing	Rock Salt Obtaining Evidence	27	0.079	.685	Working Memory Processing	Rock Salt Obtaining Evidence	21	0.299	.166
Word Recall	Heart Rate Obtaining Evidence	50	-0.253	.070	Word Recall	Heart Rate Obtaining Evidence	24	0.401	.042(≤.05)
Pattern Recall	Heart Rate Obtaining Evidence	50	-0.233	.191	Pattern Recall	Heart Rate Obtaining Evidence	24	0.040	.845
Counting Recall	Heart Rate Obtaining Evidence	50	-0.019	.893	Counting Recall	Heart Rate Obtaining Evidence	24	0.256	.206
Working Memory Composite	Heart Rate Obtaining Evidence	50	-0.159	.259	Working Memory Composite	Heart Rate Obtaining Evidence	24	0.358	.073

Working Memory Processing	Heart Rate Obtaining Evidence	50	-0.163	.254	Working Memory Processing	Heart Rate Obtaining Evidence	24	-0.011	.959
Word Recall	Spring Obtaining Evidence	18	0.058	.808	Word Recall	Spring Obtaining Evidence	23	-0.363	.075
Pattern Recall	Spring Obtaining Evidence	18	0.191	.420	Pattern Recall	Spring Obtaining Evidence	23	0.066	.753
Counting Recall	Spring Obtaining Evidence	18	0.237	.313	Counting Recall	Spring Obtaining Evidence	23	0.151	.470
Working Memory Composite	Spring Obtaining Evidence	18	0.186	.432	Working Memory Composite	Spring Obtaining Evidence	23	-0.014	.948
Working Memory Processing	Spring Obtaining Evidence	18	-0.152	.535	Working Memory Processing	Spring Obtaining Evidence	23	-0.149	.478
Word Recall	Yeast Obtaining Evidence	26	0.388	.041(≤.05)	Word Recall	Yeast Obtaining Evidence	1	-0.756	.454
Pattern Recall	Yeast Obtaining Evidence	26	0.586	.001(≤.05)	Pattern Recall	Yeast Obtaining Evidence	1	0.999	.030(≤.05)
Counting Recall	Yeast Obtaining Evidence	26	0.425	.024(≤.05)	Counting Recall	Yeast Obtaining Evidence	1	0.682	.522
Working Memory Composite	Yeast Obtaining Evidence	26	0.600	.001(≤.001)	Working Memory Composite	Yeast Obtaining Evidence	1	0.792	.418
Working Memory Processing	Yeast Obtaining Evidence	26	-0.023	.908	Working Memory Processing	Yeast Obtaining Evidence	1	0.082	.948
Word Recall	Pendulum Obtaining Evidence	74	0.243	.137	Word Recall	Pendulum Obtaining Evidence	72	0.345	.003(≤.05)
Pattern Recall	Pendulum Obtaining Evidence	74	0.135	.245	Pattern Recall	Pendulum Obtaining Evidence	72	-0.158	.182

Counting Recall	Pendulum Obtaining Evidence	74	0.293	.010(≤.05)	Counting Recall	Pendulum Obtaining Evidence	72	0.159	.178
Working Memory Composite	Pendulum Obtaining Evidence	74	0.293	.010(≤.05)	Working Memory Composite	Pendulum Obtaining Evidence	72	0.233	0.048(≤.05) corr less than control
Working Memory Processing	Pendulum Obtaining Evidence	74	0.003	.978	Working Memory Processing	Pendulum Obtaining Evidence	72	0.108	.364
Word Recall	Y8 Seed dispersal Obtaining Evidence	76	0.137	.232	Word Recall	Y8 Seed dispersal Obtaining Evidence	47	0.153	.293
Pattern Recall	Y8 Seed dispersal Obtaining Evidence	76	0.175	.126	Pattern Recall	Y8 Seed dispersal Obtaining Evidence	47	-0.088	.549
Counting Recall	Y8 Seed dispersal Obtaining Evidence	76	0.284	.012(≤.05)	Counting Recall	Y8 Seed dispersal Obtaining Evidence	47	0.028	.849
Working Memory Composite	Y8 Seed dispersal Obtaining Evidence	76	0.248	.028(≤.05)	Working Memory Composite	Y8 Seed dispersal Obtaining Evidence	47	0.055	.709
Working Memory Processing	Y8 Seed dispersal Obtaining Evidence	76	0.186	.106	Working Memory Processing	Y8 Seed dispersal Obtaining Evidence	47	-0.137	.353

The majority of the WM assessments to Investigative Obtaining Evidence Skills Science Assessment Attainment were found not to be correlated for the active group (see Table 39). For example, WM word recall and Electromagnet Obtaining Evidence were not correlated r(73)=--.110, p=.346 and WM Processing Speed and Seed Dispersal Obtaining Evidence were not correlated r(47)=-.137, p=0.353. This suggests that the WM activities do not improve Obtaining Evidence Science Investigative Skills attainment. There is an unusual negative correlation between Pattern Recall and the rock salt obtaining evidence assessment r=-.474 and p= .22. This suggests that as the pattern recall WM assessment scores increased the rock salt obtaining evidence results are decreasing. This is an interesting point and one that will be discussed

Table 118 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Analysis Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline analysis	74	0.226	.049(≤.05)	Word Recall	Baseline analysis	79	0.173	.122
Pattern Recall	Baseline analysis	74	0.029	.807	Pattern Recall	Baseline analysis	79	-0.048	.671
Counting Recall	Baseline analysis	74	-0.038	.747	Counting Recall	Baseline analysis	79	0.176	.115
Working Memory Composite	Baseline analysis	74	0.084	.470	Working Memory Composite	Baseline analysis	79	0.183	.103
Working Memory Processing	Baseline analysis	74	-0.014	.903	Working Memory Processing	Baseline analysis	79	0.209	.063
Word Recall	Heart Rate Analysis	43	0.020	.896	Word Recall	Heart Rate Analysis	24	0.240	.239

Pattern Recall	Heart Rate Analysis	43	-0.032	.836	Pattern Recall	Heart Rate Analysis	24	0.063	.759
Counting Recall	Heart Rate Analysis	43	0.230	.128	Counting Recall	Heart Rate Analysis	24	0.031	.882
Working Memory Composite	Heart Rate Analysis	43	0.138	.366	Working Memory Composite	Heart Rate Analysis	24	0.148	.471
Working Memory Processing	Heart Rate Analysis	43	0.067	.667	Working Memory Processing	Heart Rate Analysis	24	0.114	.581
Word Recall	Spring Analysis	15	0.340	.182	Word Recall	Spring Analysis	15	0.630	.007(≤.05)
Pattern Recall	Spring Analysis	15	0.353	.165	Pattern Recall	Spring Analysis	15	0.036	.890
Counting Recall	Spring Analysis	15	0.312	.223	Counting Recall	Spring Analysis	15	-0.100	.704
Working Memory Composite	Spring Analysis	15	0.353	.165	Working Memory Composite	Spring Analysis	15	0.172	.510
Working Memory Processing	Spring Analysis	15	-0.063	.817	Working Memory Processing	Spring Analysis	15	-0.086	.744
Word Recall	Yeast Analysis	26	0.162	.410	Word Recall	Yeast Analysis	1	0.189	.879
Pattern Recall	Yeast Analysis	26	0.053	.790	Pattern Recall	Yeast Analysis	1	0.540	.637
Counting Recall	Yeast Analysis	26	0.052	.793	Counting Recall	Yeast Analysis	1	0.974	.144
Working Memory Composite	Yeast Analysis	26	0.151	.443	Working Memory Composite	Yeast Analysis	1	0.924	.249
Working Memory Processing	Yeast Analysis	26	0.281	.148	Working Memory Processing	Yeast Analysis	1	0.904	.281
Word Recall	Pendulum Analysis	59	0.251	.051	Word Recall	Pendulum Analysis	68	-0.035	.776
Pattern Recall	Pendulum Analysis	59	0.031	.812	Pattern Recall	Pendulum Analysis	68	0.058	.636

Counting Recall	Pendulum Analysis	59	0.225	.081	Counting Recall	Pendulum Analysis	68	0.134	.269
Working Memory Composite	Pendulum Analysis	59	0.252	.050(≤.05)	Working Memory Composite	Pendulum Analysis	68	0.107	.378
Working Memory Processing	Pendulum Analysis	59	0.049	.709	Working Memory Processing	Pendulum Analysis	68	0.153	.206
Word Recall	Seed dispersal Analysis	72	0.194	.098	Word Recall	Seed dispersal Analysis	45	-0.161	.278
Pattern Recall	Seed dispersal Analysis	72	0.159	.176	Pattern Recall	Seed dispersal Analysis	45	0.163	.275
Counting Recall	Seed dispersal Analysis	72	0.077	.514	Counting Recall	Seed dispersal Analysis	45	-0.039	.794
Working Memory Composite	Seed dispersal Analysis	72	0.161	.170	Working Memory Composite	Seed dispersal Analysis	45	-0.041	.785
Working Memory Processing	Seed dispersal Analysis	72	0.086	.471	Working Memory Processing	Seed dispersal Analysis	45	-0.082	.590
Word Recall	Sound Analysis	No data	No data	No data	Word Recall	Sound Analysis	25	-0.562	.002
Pattern Recall	Sound Analysis	No data	No data	No data	Pattern Recall	Sound Analysis	25	-0.146	.468
Counting Recall	Sound Analysis	No data	No data	No data	Counting Recall	Sound Analysis	25	0.194	.331

Working Memory Composite	Sound Analysis	No data	No data	No data	Working Memory Composite	Sound Analysis	25	0.270	.174
Working Memory Processing	Sound Analysis	No data	No data	No data	Working Memory Processing	Sound Analysis	25	0.197	.336

None of the WM assessments to Investigative Analysis Skills Science Assessment Attainment were found not to be correlated for the active group (see Table 40). For example, WM word recall and Heart Rate Analysis were not correlated r(24)=--.240, p=.239 and WM Processing Speed and Seed Dispersal Analysis were not correlated r(45)=--.082, p=0.590. This suggests that the WM activities do not have a relationship Analysis Science Investigative Skills Attainment.

Table 119 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Evaluating Science Investigative Skills Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p	WM assessment measure	Science Investigative Skills Assessment Attainment	Df	r	p
Word Recall	Baseline Evaluating	55	0.077	.571	Word Recall	Baseline Evaluating	69	0.187	.118
Pattern Recall	Baseline Evaluating	55	0.08	.552	Pattern Recall	Baseline Evaluating	69	0.043	.722
Counting Recall	Baseline Evaluating	55	-0.078	.565	Counting Recall	Baseline Evaluating	69	0.297	.012(≤.05)

Working Memory Composite	Baseline Evaluating	55	0.002	.991	Working Memory Composite	Baseline Evaluating	69	0.306	.009(≤.05)
Working Memory Processing	Baseline Evaluating	55	0.093	.494	Working Memory Processing	Baseline Evaluating	69	0.131	.275
Word Recall	Rock Salt Evaluating	24	0.263	.194	Word Recall	Rock Salt Evaluating	9	0.191	.574
Pattern Recall	Rock Salt Evaluating	24	-0.015	.943	Pattern Recall	Rock Salt Evaluating	9	-0.097	.778
Counting Recall	Rock Salt Evaluating	24	0.043	.835	Counting Recall	Rock Salt Evaluating	9	0.121	.724
Working Memory Composite	Rock Salt Evaluating	24	0.147	.475	Working Memory Composite	Rock Salt Evaluating	9	0.053	.878
Working Memory Processing	Rock Salt Evaluating	24	-0.224	.271	Working Memory Processing	Rock Salt Evaluating	9	-0.045	.895
Word Recall	Spring Evaluating	11	0.350	.241	Word Recall	Spring Evaluating	8	-0.186	.606
Pattern Recall	Spring Evaluating	11	-0.108	.724	Pattern Recall	Spring Evaluating	8	0.677	0.032(≤.05)
Counting Recall	Spring Evaluating	11	0.253	.405	Counting Recall	Spring Evaluating	8	0.424	.222
Working Memory Composite	Spring Evaluating	11	0.230	.449	Working Memory Composite	Spring Evaluating	8	0.503	.138
Working Memory Processing	Spring Evaluating	11	0.259	.392	Working Memory Processing	Spring Evaluating	8	0.015	.967
Word Recall	Salt Evaluating	20	0.137	.542	Word Recall	Salt Evaluating	No data	No data	No data
Pattern Recall	Salt Evaluating	20	0.171	.447	Pattern Recall	Salt Evaluating	No data	No data	No data

Counting Recall	Salt Evaluating	20	0.192	.391	Counting Recall	Salt Evaluating	No data	No data	No data
Working Memory Composite	Salt Evaluating	20	0.197	.381	Working Memory Composite	Salt Evaluating	No data	No data	No data
Working Memory Processing	Salt Evaluating	20	0.049	.833	Working Memory Processing	Salt Evaluating	No data	No data	No data
Word Recall	Yeast Evaluating	23	0.207	.320	Word Recall	Yeast Evaluating	1	0.189	.879
Pattern Recall	Yeast Evaluating	23	0.257	.215	Pattern Recall	Yeast Evaluating	1	0.540	.637
Counting Recall	Yeast Evaluating	23	0.238	.253	Counting Recall	Yeast Evaluating	1	0.974	.144
Working Memory Composite	Yeast Evaluating	23	0.344	.092	Working Memory Composite	Yeast Evaluating	1	0.924	.249
Working Memory Processing	Yeast Evaluating	23	-0.048	.818	Working Memory Processing	Yeast Evaluating	1	0.904	.281
Word Recall	Reaction Series Evaluating	13	0.488	.065	Word Recall	Reaction Series Evaluating	30	0.228	.210
Pattern Recall	Reaction Series Evaluating	13	0.475	.073	Pattern Recall	Reaction Series Evaluating	30	0.037	.840
Counting Recall	Reaction Series Evaluating	13	0.207	.459	Counting Recall	Reaction Series Evaluating	30	-0.026	.887
Working Memory Composite	Reaction Series Evaluating	13	0.426	.114	Working Memory Composite	Reaction Series Evaluating	30	0.077	.673
Working Memory Processing	Reaction Series Evaluating	13	0.327	.234	Working Memory Processing	Reaction Series Evaluating	30	-0.074	.688
Word Recall	Rusting Evaluating		No data		Word Recall	Rusting Evaluating		No data	

Pattern Recall	Rusting Evaluating		No data		Pattern Recall	Rusting Evaluating		No data	
Counting Recall	Rusting Evaluating		No data		Counting Recall	Rusting Evaluating		No data	
Working Memory Composite	Rusting Evaluating		No data		Working Memory Composite	Rusting Evaluating		No data	
Working Memory Processing	Rusting Evaluating		No data		Working Memory Processing	Rusting Evaluating		No data	

The majority of the WM assessments to Investigative Evaluating Skills Science Assessment Attainment were found not to be correlated for the active group (see Table 41). For example, WM word recall and Rock Salt Evaluating were not correlated r(9)=.191, p=.574 and WM Processing Speed and Reaction Series Evaluating were not correlated r(30)=-.074, p=0.673. This suggests that the WM activities do not have a relationship with Evaluating Science Investigative Skills Attainment.

Table 120 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Physics Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Physics 1a	50	0.266	.056	Word Recall	Physics 1a	49	0.325	.020(≤.05)
Pattern Recall	Physics 1a	50	0.189	.179	Pattern Recall	Physics 1a	49	0.108	.452
Counting Recall	Physics 1a	50	0.057	.688	Counting Recall	Physics 1a	49	0.195	.169

Working Memory Composite	Physics 1a	50	0.169	.232	Working Memory Composite	Physics 1a	49	0.280	.047(≤.05)
Working Memory Processing	Physics 1a	50	0.177	.215	Working Memory Processing	Physics 1a	49	0.054	.707
Word Recall	Physics 1b	45	0.327	.025(≤.05)	Word Recall	Physics 1b	45	0.112	.453
Pattern Recall	Physics 1b	45	0.200	.177	Pattern Recall	Physics 1b	45	0.168	.259
Counting Recall	Physics 1b	45	0.246	.095	Counting Recall	Physics 1b	45	0.120	.422
Working Memory Composite	Physics 1b	45	0.300	.041(≤.05)	Working Memory Composite	Physics 1b	45	0.183	.218
Working Memory Processing	Physics 1b	45	0.255	.088	Working Memory Processing	Physics 1b	45	-0.045	.762
Word Recall	Physics 1c	48	0.284	.046(≤.05)	Word Recall	Physics 1c	45	0.196	.187
Pattern Recall	Physics 1c	48	0.208	.148	Pattern Recall	Physics 1c	45	0.112	.452
Counting Recall	Physics 1c	48	0.158	.274	Counting Recall	Physics 1c	45	0.093	.536
Working Memory Composite	Physics 1c	48	0.234	.102	Working Memory Composite	Physics 1c	45	0.189	.203
Working Memory Processing	Physics 1c	48	0.132	.364	Working Memory Processing	Physics 1c	45	-0.159	.292
Word Recall	Physics 2d	21	0.308	.152	Word Recall	Physics 2d	49	0.191	.179
Pattern Recall	Physics 2d	21	0.341	.111	Pattern Recall	Physics 2d	49	0.024	.865
Counting Recall	Physics 2d	21	0.453	.030(≤.05)	Counting Recall	Physics 2d	49	0.090	.529
Working Memory Composite	Physics 2d	21	0.397	.061	Working Memory Composite	Physics 2d	49	0.139	.330

Working Memory Processing	Physics 2d	21	0.206	.358	Working Memory Processing	Physics 2d	49	0.141	.329
Word Recall	Physics 2e	21	0.324	.132	Word Recall	Physics 2e	43	0.103	.499
Pattern Recall	Physics 2e	21	0.166	.448	Pattern Recall	Physics 2e	43	0.056	.714
Counting Recall	Physics 2e	21	0.356	.096	Counting Recall	Physics 2e	43	0.157	.302
Working Memory Composite	Physics 2e	21	0.312	.147	Working Memory Composite	Physics 2e	43	0.180	.237
Working Memory Processing	Physics 2e	21	0.391	.072	Working Memory Processing	Physics 2e	43	0.080	.607

The majority of the WM assessments to Physics Home Work Science Assessment Attainment were found not to be correlated for the active group (see Table 42). For example, WM word recall and Physics Home Work 1b were not correlated r(45)=.112, p=.453 and WM Processing Speed and Physics Home Work 2e were not correlated r(43)=.080, p=0.607. However, WM word recall & Physics Home Work 1a were correlated r(49)= .325, p=.020(≤.05) & WM composite & Physics Home Work 1a were correlated r(49)= .280, p=.047(≤.05).

On the other hand, the statistical analysis showed the control group WM assessments had some significant correlations with Physics Home Work. WM word recall & Physics Home Work 1b were correlated r(45)= .327, p=.25(≤.05); WM composite & Physics Home Work 1b were correlated r(45)= .300, p=.46(≤.05); WM word recall & Physics Home Work 1c were correlated r(48)= .284, p=.046(≤.05) and WM counting recall & Physics Home Work 2d were correlated r(21)= .453, p=.030(≤.05).

This suggests that the WM activities do have a relationship with Physics Home Work Science Attainment. The WM activities appear to show a relationship between WM assessment and Physics

Home Work 1a. Contrary to that conclusion is that the normal way of teaching seems to indicate a relationship between WM assessments and Physics Home Works 1b, 1c and 2d.

Table 121 The outcomes of correlation coefficient tests between Post-test WM assessment measures and Biology Science Homework Assessment Attainment for the Control and the Active conditions

Control Group					Active Group				
WM assessment measure	Science Homework Assessment Attainment	Df	r	p	WM assessment measure	Science Homework Assessment Attainment	Df	r	p
Word Recall	Biology 1a	49	0.056	.697	Word Recall	Biology 1a	48	0.253	.077
Pattern Recall	Biology 1a	49	-0.068	.636	Pattern Recall	Biology 1a	48	-0.176	.222
Counting Recall	Biology 1a	49	-0.047	.746	Counting Recall	Biology 1a	48	0.042	.772
Working Memory Composite	Biology 1a	49	-0.017	.907	Working Memory Composite	Biology 1a	48	0.057	.697
Working Memory Processing	Biology 1a	49	0.145	.314	Working Memory Processing	Biology 1a	48	0.183	.209
Word Recall	Biology 1b	33	-0.032	.857	Word Recall	Biology 1b	26	0.410	.030(≤.05)
Pattern Recall	Biology 1b	33	-0.197	.257	Pattern Recall	Biology 1b	26	-0.234	.231
Counting Recall	Biology 1b	33	-0.192	.270	Counting Recall	Biology 1b	26	-0.109	.580
Working Memory Composite	Biology 1b	33	-0.161	.355	Working Memory Composite	Biology 1b	26	-0.007	.971
Working Memory Processing	Biology 1b	33	0.168	.342	Working Memory Processing	Biology 1b	26	0.358	.062

Word Recall	Biology 2c		No data	No data	Word Recall	Biology 2c	18	0.557	.011(≤.05)
Pattern Recall	Biology 2c		No data	No data	Pattern Recall	Biology 2c	18	-0.156	.511
Counting Recall	Biology 2c		No data	No data	Counting Recall	Biology 2c	18	0.093	.696
Working Memory Composite	Biology 2c		No data	No data	Working Memory Composite	Biology 2c	18	0.183	.441
Working Memory Processing	Biology 2c		No data	No data	Working Memory Processing	Biology 2c	18	0.120	.616
Word Recall	Biology 2d		No data	No data	Word Recall	Biology 2d	17	0.344	.149
Pattern Recall	Biology 2d		No data	No data	Pattern Recall	Biology 2d	17	-0.090	.716
Counting Recall	Biology 2d		No data	No data	Counting Recall	Biology 2d	17	-0.045	.854
Working Memory Composite	Biology 2d		No data	No data	Working Memory Composite	Biology 2d	17	0.057	.816
Working Memory Processing	Biology 2d		No data	No data	Working Memory Processing	Biology 2d	17	0.230	.343

The majority WM assessments to Biology Home Work Science Assessment Attainment were found not to be correlated for the active group (Table 121 p. 556). For example, WM word recall and Biology Home Work 1a were not correlated r(48)=.253, p=.077 and WM Processing Speed and Biology Home Work 2d were not correlated r(17)=.230, p=0.343. This suggests that the WM activities do not have a relationship with Biology Home Work Science Attainment.

In summary the majority of WM assessments are not positively correlated to the Science attainment data of the active group. This suggests that WM does not have a relationship to the

Science Attainment of the active group. The exception being the three correlations between the WM assessment and the End of Y7 and End of Y8 Report Grade. Regression analysis (Tables 16 a & b) was then carried out on these. This indicates that WM is contributing to 23.4% and 26.9% to Y7 End of Report Grade and Y8 End of Report Grade respectively. However, the control group's regression analysis for WM assessment and the End of Y8 Report Grade showed a similar percentage of 24.5% leading to the conclusion that the WM activities do not have a relationship with End of Y8 science Report Grades.

H: 4.3.1 Analysis of the dependent (paired) t-test for the pre-test and post-test WM test assessments

Table 122 The results of a dependent (paired t-test) on the pre-test and post-test results of the WM test assessments of the control group

WM Test Component Assessed	Pre-test		Post-test		df	t	p
	M	SD	M	SD			
Word Recall	103.8675	13.50047	105.1220	14.44563	80	-0.877	.383
Pattern Recall	97.5542	10.98586	100.5366	11.23948	80	-2.742	.008(≤.05)
Counting Recall	100.6145	17.08360	104.3171	18.76619	80	-2.404	.019 (≤.05)
WM Composite	102.2410	12.92812	105.2927	14.84196	80	-2.856	0.005(≤05)
WM Processing Speed	92.6988	11.47185	95.9012	12.02664	79	-1.966	0.053

The results from the pre-test Word Recall (M=103.8675, SD=13.50047) and post-test Word Recall (M=105.1220, SD=14.44563) WM Test assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Summative Science assessment, t(80)=-0.877, p=.383

The results from the pre-test Pattern Recall (M=97.5542, SD=10.98586) and post-test Pattern Recall (M=100.5366, SD=11.23948) WM Test assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(80)=-2.742, p=.008

The results from the pre-test Counting Recall (M=100.6145, SD=17.08360) and post-test Counting Recall (M=104.3171, SD=18.76619) WM Test assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(80)=-2.404, p=.019

The results from the pre-test WM Composite (M=102.2410, SD=12.92812) and post-test WM Composite (M=105.2927, SD=14.84196) WM Test assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(75)=-2.856, p=.005

The results from the pre-test WM Processing Speed (M=92.6988, SD=11.47185) and post-test WM Processing Speed (M=95.9012, SD=12.02664) WM Test assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Summative Science assessment, t(79)=-1.966, p=.053

Table 123 The results of a dependent (paired t-test) on the pre-test and post-test results of the WM test assessments of the active group

WM Test Component Assessed	Pre-test		Post-test		df	t	p
	M	SD	M	SD			
Word Recall	104.3544	10.55029	104.9756	12.85049	75	-0.367	.714
Pattern Recall	98.9873	11.15680	102.7561	9.96359	75	-3.461	.001(≤.001)
Counting Recall	100.0506	16.23458	104.6098	18.58830	75	-2.975	.004(≤05)
WM Composite	102.5949	10.48383	105.9390	12.03426	75	-3.531	.001(≤001)
WM Processing Speed	94.7564	10.33238	96.5802	11.10052	73	-1.754	.084

The results from the pre-test Word Recall (M=104.3544, SD=10.55029) and post-test Word Recall (M=104.9756, SD=12.85049) WM Test assessment indicate that doing the WM activities in their Science lessons results in no significant improvement in the Summative Science assessment, t(75)=-0.367, p=.714

The results from the pre-test Pattern Recall (M=98.9873, SD=11.15680) and post-test Pattern Recall (M=102.7561, SD=9.96359) WM Test assessment indicate that doing the WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(75)=-3.461, p=.001

The results from the pre-test Counting Recall (M=100.0506, SD=16.23458) and post-test Counting Recall (M=104.6098, SD=18.58830) WM Test assessment indicate that doing the WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(75)=-2.975, p=.004

The results from the pre-test WM Composite (M=102.5949, SD=10.48383) and post-test WM Composite (M=105.9390, SD=12.03426) WM Test assessment indicate that doing the WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(75)=-3.531, p=.001

The results from the pre-test WM Processing Speed (M=94.7564, SD=10.33238) and post-test WM Processing Speed (M=96.5802, SD=11.10052) WM Test assessment indicate that doing the WM activities in their Science lessons results in no significant improvement in the Summative Science assessment, t(73)=-1.754, p=.084

The control and the active group's dependent t-tests on the WM pre-test and post-test assessment indicate that although they are not significantly different to each other(see independent t-test section) the active group have a do not have a more significant difference (when looking at the t-values) than that of the control group for WM tests Pattern Recall, Counting Recall and WM Composite. This is a indicates that the WM activities may not have an impact on the WM of students.

H: 4.3.2 Analysis of the dependent (paired) t-test for the pre-test and post-test Science attainment assessments

Table 124 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science test assessments of the control group

Science Attainment Component Assessed	Pre-test (Y7 test 1)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Test 2	7.4322	0.11055	7.4685	0.09486	58	-2.442	.018 (≤.05)
Post-test Y7 Test 3			7.4472	0.08683	25	0.000	1.000
Post-test Y7 End of Year Test			7.4345	0.12362	27	1.613	.118
Post-test Y7 End of Year Report grade			7.4599	0.12024	58	-0.890	.377
Post-test Y8 Test 1			7.6356	0.13434	58	-13.452	.000(≤.001) Same active
Post-test Y8 Test 2			7.6100	0.11808	58	-9.090	.000(≤.001) Same active
Post-test Y8 End of Year Report Grade			7.6163	0.12518	58	-14.198	.000(≤.001) Same active

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y7 Test 2 (M=7.4685, SD=0.09486) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(58)=-2.442, p=.018

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y7 Test 3 (M=7.4472, SD=0.08683) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Summative Science assessment, t(25)=0.000, p=1.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y7 End of Year Test (M=7.4345, SD=0.12362) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Summative Science assessment, t(27)=1.613, p=.118

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative End of Y7 Report Grade (M=7.4599, SD=0.12024) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Summative Science assessment, t(58)=-0.890, p=.377

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y8 Test 1 (M=7.6356, SD=0.13434) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(58)=-13.452, p=.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative Y8 Test 2 (M=7.6100, SD=0.11808) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(58)=-9.090, p=.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4322, SD=0.11055) and post-test Summative End of Year 8 Report Grade (M=7.6163, SD=0.12518) Science Summative assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Summative Science assessment, t(58)=-14.198, p=.000

Table 125 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science test assessments of the active group

Science Attainment Component Assessed	Pre-test (Y7 test 1)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Test 2	7.4093	0.08489	7.4390	0.10989	80	-2.517	.014(p≤.05)
Post-test Y7 Test 3			7.4156	0.08060	55	-2.879	.006(p≤.05)
Post-test Y7 End of Year Test			7.4365	0.11323	85	-0.882	.380
Post-test Y7 End of Year Report grade			7.4522	0.12084	85	-4.346	.000(p≤.001)
Post-test Y8 Test 1			7.6442	0.13426	80	-13.686	.000(p≤.001)
Post-test Y8 Test 2			7.6571	0.11542	79	-15.239	.000(p≤.001)
Post-test Y8 End of Year Report Grade			7.6156	0.12078	83	-14.198	.000(p≤.001)

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y7 Test 2 (M=7.4390, SD=0.10989) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(80)=-2.517, p=.014

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y7 Test 3 (M=7.4156, SD=0.08060) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(55)=-2.879, p=.006

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y7 End of Year Test (M=7.4365, SD=0.11323) Science Summative assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Summative Science assessment, t(85)=-0.882, p=.380

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative End of Y7 Report Grade (M=7.4522, SD=0.12084) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(85)=-4.346, p=.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y8 Test 1 (M=7.6442, SD=0.13426) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(80)=-13.686, p=.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative Y8 Test 2 (M=7.6571, SD=0.11542) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(79)=-15.239, p=.000

The results from the pre-test Science Summative Assessment Y7 Test 1 (M=7.4093, SD=0.08489) and post-test Summative End of Y8 Report Grade (M=7.6571, SD=0.11542) Science Summative assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Summative Science assessment, t(83)=-14.198, p=.000

The control and the active group's dependent t-tests on the Science Summative pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the active group have a more significant difference (when looking at the t-values) than that of the control group for Y7 Test 2, Y8 Test 1 and Y8 Test 3. This is a small indicator that the WM activities may have an impact on the Science attainment of the students in the active group.

Table 126 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Planning Skills assessments of the control group

Science Attainment Component Assessed	Pre-test (Investigative Skill Planning)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Electromagnet Planning	7.3107	0.10415	7.5207	0.09403	26	-13.301	.000(p≤.001)
Post-test Y7 Yeast Planning			7.5103	0.13455	26	-6.802	.000(p≤.001)
Post- test Y8 Planning Reaction Series			7.5276	0.09963	26	-5.848	.000(p≤.001)
Post-test Y8 Planning Sound			NA	NA	NA	NA	NA

The results from the pre-test Planning (M=7.3107, SD=0.10415) and post-test Electromagnet Planning (M=7.5207, SD=0.09403) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(26)=-13.301, p=.000

The results from the pre-test Planning (M=7.3107, SD=0.10415) and post-test Yeast Planning (M=7.5103, SD=0.13455) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(26)=-6.802, p=.000

The results from the pre-test Planning (M=7.3107, SD=0.10415) and post-test Reaction Series Planning (M=7.5276, SD=0.09963) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(26)=-5.848, p=.000

Table 127 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Planning Skills assessments of the active group

Science Attainment Component Assessed	Pre-test (Investigative Skill Planning)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Electromagnet Planning	7.4235	0.07949	7.4646	0.15445	74	-2.035	.045(p≤.05)
Post-test Y7 Yeast Planning			7.5667	0.11547	2	-1.000	.423
Post- test Y8 Planning Reaction Series			7.5764	0.15982	49	-5.995	.000(p≤.001)
Post-test Y8 Planning Sound			7.5172	0.12268	24	-3.079	.005(p≤.05)

The results from the pre-test Planning (M=7.4235, SD=0.07949) and post-test Electromagnets Planning (M=7.4646, SD=0.15445) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Planning Science skills assessment, t(74)=-2.035, p=.045

The results from the pre-test Planning (M=7.4235, SD=0.07949) and post-test Yeast Planning (M=7.5667, SD=0.11547) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Planning Science skills assessment, t(2)=-1.000, p=.423

The results from the pre-test Planning (M=7.4235, SD=0.07949) and post-test Reaction Series Planning (M=7.5764, SD=0.15982) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Planning Science skills assessment, t(49)=-5.995, p=.000

The results from the pre-test Planning (M=7.4235, SD=0.07949) and post-test Sound Planning (M=7.5172, SD=0.12268) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Planning Science skills assessment, t(24)=-3.079, p=.005

The control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the control have a more significant difference (when looking at the t-values) than that of the active group for the Planning in the Electromagnet, Yeast and Sound Investigations. This is a small indicator that the WM activities may have little or no an impact on the Science Skills attainment of the students in the active group.

Table 128 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Obtaining Evidence Skills assessments of the control group

Science Attainment Component Assessed	Pre-test (Investigative Skill Obtaining Evidence)		Post-test (see first column)		df	t	P
	M	SD	M	SD			
Post-test Y7 Electromagnets Obtaining Evidence	7.365	0.140	7.507	0.088		Means completely different	
Post-test Y7 Rock Salt Obtaining Evidence			7.507	0.087		Means completely different	
Post-test Y7 Heart Rate Obtaining Evidence			7.524	0.060	28	-12.872	.000(p≤.001)

							Same as active group
Post-test Y7 Spring Obtaining Evidence			7.581	0.094	24	-12.626	.000(p≤.001)
Post-test Y7 Yeast Obtaining Evidence			7.503	0.132	26	-2.068	.049(p≤.05) Active group more significant
Post-test Y8 Pendulum Obtaining Evidence			7.560	0.154	51	-6.422	.000(p≤.001) Active group Same
Post-test Y8 Seed dispersal Obtaining Evidence			7.578	0.147	55	-9.781	.000(p≤.001) Active group Same

The results from the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Heart Rate Obtaining Evidence (M=7.5237, SD=0.05971) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(28)=-12.872, p=.000

The results from the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Spring Obtaining Evidence (M=7.5808, SD=0.09389) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(24)=-12.626, p=.000

The results from the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Yeast Obtaining Evidence (M=7.5034, SD=0.13224) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(26)=-2.068, p=.049

The results from the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Pendulum Obtaining Evidence (M=7.5595, SD=0.15376) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(51)=-6.422, p=.000

The results from the pre-test Obtaining Evidence (M=7.3649, SD=0.13950) and post-test Seed Dispersal Obtaining Evidence (M=7.5779, SD=0.14665) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(55)=-9.781, p=.000

Table 129 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Obtaining Evidence Skills assessments of the active group

Science Attainment Component Assessed	Pre-test (Investigative Skill Obtaining Evidence)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Electromagnets Obtaining Evidence	7.3938	0.10948	7.5150	0.12232	73	-7.086	.000(p≤.001) Control means competely different
Post-test Y7 Rock Salt Obtaining Evidence			7.4667	0.10901	23	-0.189	.852

Post-test Y7 Heart Rate Obtaining Evidence			7.5862	0.07894	26	-10.354	.000(p≤.001) Same as control
Post-test Y7 Spring Obtaining Evidence			7.5172	0.04682	25	-3.348	.003(p≤.05) Control more significant
Post-test Y7 Yeast Obtaining Evidence			7.6667	0.05774	2	-5.000	.038(p≤.05) Active more significant
Post-test Y8 Pendulum Obtaining Evidence			7.6630	0.15846	72	-11.103	.000(p≤.001) Same significance
Post-test Y8 Seed dispersal Obtaining Evidence			7.5423	0.13626	46	-7.567	.000(p≤.001) Same significance

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Electromagnets Obtaining Evidence (M=7.5150, SD=0.12232) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(73)=-7.086, p=.000

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Rock Salt Obtaining Evidence (M=7.4667, SD=0.10901) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Obtaining Evidence Science skills assessment, t(23)=-0.189, p=.852

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Heart Rate Obtaining Evidence (M=7.5862, SD=0.07894) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(26)=-10.354, p=.000

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Spring Obtaining Evidence (M=7.5172, SD=0.04682) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(25)=-3.348, p=.003

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Yeast Obtaining Evidence (M=7.6667, SD=0.05774) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(2)=-5.000, p=.038

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Pendulum Obtaining Evidence (M=7.6630, SD=0.15846) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(72)=-11.103, p=.000

The results from the pre-test Obtaining Evidence (M=7.3938, SD=0.10948) and post-test Seed Dispersal Obtaining Evidence (M=7.5423, SD=0.13626) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Obtaining Evidence Science skills assessment, t(46)=-7.567, p=.000

The control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the control have a more significant difference (when looking at the t-values) than that of the active group for the Obtaining Evidence in the Electromagnet, Rock Salt, Heart Rate, Spring, Yeast and Pendulum Investigations. This is a small indicator that the WM activities may have little or no an impact on the Science Skills attainment of the students in the active group.

Table 130 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Analysis Skills assessments of the control group

Science Attainment Component Assessed	Pre-test (Investigative Skill Analysis)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Heart Rate Analysis	7.3807	0.11735	7.4288	0.10163	50	-1.800	.078
Post-test Y7 Spring Analysis			7.4304	0.11455	21	-5.923	.000(p≤.001)
Post-test Y7 Yeast Analysis			7.3759	0.16617	23	-0.249	.806
Post-test Y8 Pendulum Analysis			7.4652	0.19255	59	-3.040	.004(p≤.05) Active more signif
Post-test Y8 Seed dispersal Analysis			7.5512	0.14076	74	-9.436	.000(p≤.001)
Post-test Y8 Sound Analysis			NA	NA	NA	NA	NA

The results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Heart Rate Analysis (M=7.4288, SD=0.10163) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Analysis Science skills assessment, t(50)=-1.800, p=.078

The results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Spring Analysis (M=7.4304, SD=0.11455) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Analysis Science skills assessment, t(21)=-5.923, p=.000

The results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Yeast Analysis (M=7.3759, SD=0.16617) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Analysis Science skills assessment, t(23)=-0.249, p=.806

The results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Pendulum Analysis (M=7.4652, SD=0.19255) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Analysis Science skills assessment, t(59)=-3.040, p=.004

The results from the pre-test Analysis (M=7.3807, SD=0.11735) and post-test Seed Dispersal Analysis (M=7.5512, SD=0.14076) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Analysis Science skills assessment, t(74)=-9.436, p=.000

Table 131 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Analysis Skills assessments of the active group

Science Attainment Component Assessed	Pre-test (Investigative Skill Analysis)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Heart Rate Analysis	7.4395	0.08849	7.5357	0.18301	25	-1.910	.068
Post-test Y7 Spring Analysis			7.44	0.122	16	0.160	.875

Post-test Y7 Yeast Analysis			7.5667	0.11547	2	0.000	1.000
Post-test Y8 Pendulum Analysis			7.5390	0.18364	73	-4.718	.000(p≤.001)
Post-test Y8 Seed dispersal Analysis			7.4920	0.14824	48	-2.184	.034(p≤.05) Control more significant
Post-test Y8 Sound Analysis			7.5345	0.11109	28	-7.117	.000(p≤.001) No comparative data

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Heart Rate Analysis (M=7.5357, SD=0.18301) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Analysis Science skills assessment, t(25)=-1.910, p=.068

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Spring Analysis (M=7.44, SD=0.122) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Analysis Science skills assessment, t(16)=0.16, p=.875

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Yeast Analysis (M=7.5667, SD=0.11547) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Analysis Science skills assessment, t(2)=0.000, p=1.000

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Pendulum Analysis (M=7.5390, SD=0.18364) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Analysis Science skills assessment, t(73)=-4.718, p=.000

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Seed Dispersal Analysis (M=7.4920, SD=0.14824) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(48)=-2.184, p=.034

The results from the pre-test Analysis (M=7.4395, SD=0.08849) and post-test Pendulum Analysis (M=7.5345, SD=0.11109) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(28)=-7.117, p=.000

The control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that they are not significantly different to each other (see independent t-test section) nor does either group have more of a significant difference (when looking at the t-values). This outcome indicates that whether students are exposed to WM activities or traditional teaching methods makes no difference in Analysis Science Investigative Skills attainment.

Table 132 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Evaluation Skills assessments of the control group

Science Attainment Component Assessed	Pre-test (Investigative Skill Evaluating)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Rock Salt Evaluating	7.3365	0.09887	7.3593	0.11184	26	2.467	0.021(p≤.05)
Post-test Y7 Spring Evaluating			7.3737	0.12842	17	-4.242	0.001(p≤.001)

Post-test Y7 Salt Evaluating			7.4556	0.10860	26	-10.448	0.000(p≤.001) No comparable data
Post-test Y7 Yeast Evaluating			7.3577	0.09021	3	-2.611	0.080
Post-test Y8 Reaction Series Evaluating			7.4600	0.09103	2	-7.000	0.020(p≤.05)

The results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Rock Salt Evaluating (M=7.3593, SD=0.11184) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(26)=2.467, p=.0.021

The results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Spring Evaluating (M=7.3737, SD=0.12842) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Evaluating Science skills assessment, t(17)=-4.242, p=.0.001

The results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Salt Evaluating (M=7.4556, SD=0.10860) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(26)= -10.448, p=.000(p≤.001)

The results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Yeast Evaluating (M=7.3577, SD=0.09021) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in no significant improvement in the Evaluating Science skills assessment, t(3)= -2.611, p=.080

The results from the pre-test Evaluating (M=7.3365, SD=0.09887) and post-test Reaction Series Evaluating (M=7.4600, SD=0.09103) Science skills assessment indicate that having traditional teaching methods in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(2)=-7.000, p=.0.020(p≤.05)

Table 133 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Investigative Evaluation Skills assessments of the active group

Science Attainment Component Assessed	Pre-test (Investigative Skill Evaluating)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Post-test Y7 Rock Salt Evaluating	7.3842	0.09529	7.48	0.122	10	-1.517	.160
Post-test Y7 Spring Evaluating			7.37	0.149	10	0.149	.884
Post-test Y7 Salt Evaluating			NA	NA	NA	NA	NA
Post-test Y7 Yeast Evaluating			7.4000	0.17321	2	1.000	.423
Post-test Y8 Reaction Series Evaluating			7.4743	0.17037	30	-2.118	.043 (p≤.05) Not as significant as control

The results from the pre-test Evaluating (M=7.3842, SD=0.09529) and post-test Rock Salt Evaluating (M=7.48, SD=0.122) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Evaluating Science skills assessment, t(10)=-1.517, p=.160

The results from the pre-test Evaluating (M=7.3842, SD=0.09529) and post-test Spring Evaluating (M=7.37, SD=0.149) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Evaluating Science skills assessment, t(10)=0.149, p=.884

The results from the pre-test Evaluating (M=7.3842, SD=0.09529) and post-test Yeast Evaluating (M=7.4000, SD=0.17321) Science skills assessment indicate that completing WM activities in their Science lessons results in no significant improvement in the Evaluating Science skills assessment, t(2)=1.000, p=.423

The results from the pre-test Evaluating (M=7.3842, SD=0.09529) and post-test Reaction Series Evaluating (M=7.4743, SD=0.17037) Science skills assessment indicate that completing WM activities in their Science lessons results in a significant improvement in the Evaluating Science skills assessment, t(30)=-2.118, p=.0.43

The control and the active group's dependent t-tests on the Science Investigative Skills pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the control have a more significant difference (when looking at the t-values) than that of the active group for the Evaluating in the Rock Salt, Spring, Yeast and Reaction Series Investigations. This is a small indicator that the WM activities may have little or no an impact on the Science Skills attainment of the students in the active group.

Table 134 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Chemistry a Home Work assessment of the control group

Science Attainment Component Assessed	Pre-test (Chemistry 1a)		Post-test (see first column)		df	t	p
	M	SD	M	SD			

Chemistry 2a	7.3875	0.12801	7.4621	0 .21114	27	-2.684	.012(p≤.05)

The results from the pre-test (M=7.3875, SD=0.12801) and post-test (M=7.4621, SD=0.21114) Chemistry homework a indicate having traditional teaching methods in their Science lessons results in a significant improvement in Chemistry b homework, t(27)=-2.684, p=.001

Table 135 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Chemistry a Home Work assessment of the active group

Science Attainment Component Assessed	Pre-test (Chemistry 1a)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Chemistry 2a	7.4175	0.12265	7.4836	0.24173	49	-2.792	.007(p≤.05)

The results from the pre-test (M=7.4175, SD=0.12265) and post-test (M=7.4836, SD=0.24173) Chemistry homework a indicate that completing WM activities in their Science lessons results in a significant improvement in Chemistry homework a, t(49)=-2.792, p=.007

In summary the control and the active group's dependent (paired) t-tests on the WM & Science Summative pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section) the active group have a more significant difference (when looking at the t-values) than that of the control group for some WM tests & some summative Science assessment attainment (see Tables 17, 119, 125). However, the differences between the active and control group are not clear, neither are the correlation patterns evident from the data analysis. This is a small indicator that the WM activities may have an impact on the WM of students and Science attainment in the active group. However, there is little evidence to suggest that WM activities have any impact on Science Investigative Skills or Chemistry homework attainment. On the other hand, the WM activities have not impacted negatively on the student's science attainment. The quantitative data, when looked at in the context of the perception questionnaires and the qualitative data may lead to different conclusions.

Table 136 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Chemistry b Home Work assessment of the control group

Science Attainment Component Assessed	Pre-test (Chemistry 1b)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Chemistry 2b	7.4786	0.17026	7.5241	0.24002	27	-3.742	.001(p≤.001)

The results from the pre-test (M=7.4786, SD=0.17026) and post-test (M=7.5241, SD=0.24002) Chemistry homework b indicate having traditional teaching methods in their Science lessons results in a significant improvement in Chemistry b homework, t(27)=-3.742, p=.001

Table 137 The results of a dependent (paired t-test) on the pre-test and post-test results of the Science Chemistry b Home Work assessment of the active group

Science Attainment Component Assessed	Pre-test (Chemistry 1b)		Post-test (see first column)		df	t	p
	M	SD	M	SD			
Chemistry 2b	7.5807	0.15634	7.5431	0.24142	50	0.983	0.330

The results from the pre-test (M=7.5807, SD=0.15634) and post-test (M=7.5431, SD=0.24142) Chemistry homework b indicate that completing WM activities in their Science lessons results in no significant improvement in Chemistry homework, $t(50)=0.983$, $p=.330$

The control and the active group's dependent t-tests on the Science Chemistry Homework pre-test and post-test assessment indicate that although they are not significantly different to each other (see independent t-test section). The Chemistry a homework shows (if looking at the t and p values) that for Chemistry Homework 1a the active group had a bigger difference, however in the Chemistry Homework 1b the control group had a bigger difference. This outcome indicates that whether students are exposed to WM activities or traditional teaching methods makes no difference in Science Chemistry Homework Attainment.

H: 4.5.6 Analysis of Whole Staff Questionnaire

The whole school staff was invited to complete a questionnaire (Appendix G). A decision was taken to not give the cleaners or the canteen staff the whole staff questionnaire. This was because the cleaners do not work during school hours and the canteen staff have limited contact with the Year 7s as our canteen serving system is so fast. In the first year there were a total of 33 support staff who completed the whole school staff questionnaire from a wide range of job roles where these colleagues come into contact with Year 7 students. In the second year of the study 36 support staff completed the questionnaire from a wide range of roles within the school including the site team, administrators and teaching assistants

There was a total of 48 teaching staff who completed the whole school staff questionnaire in the first year. In the second year 67 teachers completed the whole staff questionnaire. In both years a wide range of teaching roles including SLT, HOH, HOD, main scale teachers, NQT and Trainee teachers completed the questionnaire; and

In the 2018-2019 academic year there were a total number of 139 staff members (excluding canteen and cleaning staff). In the 2018-2019 academic year a total of 81 staff members filled in and returned the questionnaire. This is broadly representative of the staff at the research school.

In the 2019-2020 academic year there were 130 staff members (excluding canteen and cleaning staff). In the academic year 2019-2020 103 staff members returned the questionnaire. This is a higher proportion of the overall staff numbers and hence more representative than the first year.

The whole staff questionnaire gives two insights. One into the extent that WM, its' impact on learning and the perception of the efficacy of the Science activities to develop WM. The other is to establish the exposure to the students in the research study to memory (WM) information and activities; this is for the purpose of the transparency of the research study. The responses from the support staff for both years of the research study can be seen in Table 138.

Over the two years the support staff spoke to the students in the research study informally about memory (18.2% & 22.2% in the first and second year respectively). No support staff held a formal memory activity in the first year, and this only rose slightly to 5.6%. In both years a very low percentage of support staff completed WM activities with the students (3% & 2.8% in concurrent years). A high minority of (30.3% in the first year and 44.4% in the second year) support staff witnessed WM activities (not in Science) being done with the research students. This pattern is echoed for other year groups (not the research study students) being exposed to WM activities (not in Science) 21.1% in the first year, rising to 44.4% in the second year.

Table 138 The Support Staff Responses to the whole staff questionnaire from both years of the research study

Statement	First Year Support Staff Response to Statements (Percentage %*)	Second Year Support Staff Response to Statements (Percentage %*)

	Yes	Don't Know	No	Yes	Don't Know	No
I have heard of working memory	63.6		30.3	88.9		11.1
I am aware that working memory is linked to learning	63.6	3.0	27.3	88.9	2.8	8.3
I have spoken to Year 7/8 students this year informally about memory	18.2	3.0	72.7	22.2	2.8	75.0
I have led an activity in a class, tutor time or assembly about memory this year with Year 7/8s			90.9	5.6		94.4
I use working memory activities with the current Year 7/8 students	3.0		90.9	2.8	2.8	88.9
I think developing working memory has a positive impact on learning	66.7	21.2	6.1	83.3	11.1	2.8
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7/8 students	30.3	12.1	51.5	44.4	16.7	38.9
This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (not Year 7/8)	21.2	12.1	60.6	44.4	13.9	41.7
I think the science lesson structure to develop working memory has the same impact as traditional teaching methods	6.1	69.7	18.2	11.1	50.0	38.9
I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods	3.0	69.7	21.2	58.3	38.9	2.8

*Some of the percentages do not add up to 100 as some members of support staff did not answer that specific question

Table 138 shows over the two years that the majority of support staff have heard of Working Memory and that it can be linked to learning; this increases in the second year (63.6% increasing to 88.9%). This pattern continues when the support staff are asked if they think developing WM has a positive impact on learning (in the first year the majority of 66.7% stated yes this increases to & 83.3% in the second year). The vast majority of the support staff over the two years said they had not conducted WM activities with the students in the research cohort (90.9% & 88.9%. in the first year and second year respectively). In the first year 18.2 % of the support staff state they do not think that the Science lesson structure to develop WM has the same impact as the normal way of teaching. This increases to 38.9% in the second year. The response to the statement "I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods" is very similar to the response to the statement, in the first year with a negative response at 21.2%, but swings to a very positive 58.3% stating yes in the second year. This is unexpected as the whole staff are aware that this is current research and warrants further discussion. The researcher bias and the Hawthorne effect may be occurring within these responses and this will be discussed within the discussion and limitations of the study later on in the thesis.

Table 139 The Teaching Staff Responses to the whole staff questionnaire from both years of the research study

Statement	First Year Teaching Staff Response to Statements (Percentage %*)			Second Year Teaching Staff Response to Statements (Percentage %*)		
	Yes	Don't Know	No	Yes	Don't Know	No
I have heard of working memory	100	0	0	98.5	0.0	1.5
I am aware that working memory is linked to learning	100	0	0	98.5	1.5	0.0
I have spoken to Year 7/8 students this year informally about memory	64.6	0	35.4	49.3	0.0	50.7
I have led an activity in a class, tutor time or assembly about memory this year with Year 7/8s	47.9	0	50.0	37.3	1.5	61.2
I use working memory activities with the current Year 7/8 students	41.7	2.1	56.3	40.3	4.5	53.7
I think developing working memory has a positive impact on learning	83.3	14.6	2.1	89.6	9.0	1.5
I have seen colleagues (who are not Science teachers) using activities to develop working memory with the current Year 7/8 students	35.4	4.2	60.4	34.3	11.9	52.2
This academic year I have seen colleagues (who are not Science teachers) using activities to develop working memory with students in other years (not Year 7/8)	31.3	6.3	60.4	43.3	9.0	46.3

I think the science lesson structure to develop working memory has the same impact as traditional teaching methods	18.8	79.2	2.1	11.9	59.7	26.9
I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods	31.3	66.7	2.1	44.8	52.2	1.5

*Some of the percentages do not add up to 100 as some members of support staff did not answer that specific question

The responses from the teaching staff for both years of the research study can be seen in Table 139. Over the two years the large percentages of teaching staff spoke to the students in the research study informally about memory (64.6% & 49.3% in the first and second year respectively). A large minority of teaching staff led a formal activity about memory with the students in the research study in both years (47.9% in the first year and 37.3% in the second year of the study. In the first year 41.7% of teaching staff were conducting WM activities with the students in the research study, this only decreases slightly to 40.3% in the second year. A large minority of (35.4% in the first year and 34.3% in the second year) teaching staff witnessed WM activities (not in Science) being conducted with the research students. This pattern is echoed for other teaching staff being observed with other year groups (not the research study students) using WM activities (not in Science) 31.2% in the first year, rising to 43.3% in the second year. This evidence suggests that the research cohort of students are being exposed to memory information and WM activities from other sources. Analysis of the comments of the questionnaire (see Appendix F) revealed that the teachers of the English, Mathematics and Geography departments all stating Year 7 experience Working Memory activities in at least some of their lessons. Furthermore, the RPE department stating that the Year 7s do a 10-lesson mindfulness course and that Year 7s attend a lunchtime mindfulness club. There is evidence to support the link between mindfulness and Working Memory (e.g., Chambers, Chuen Yee Lo, & Allen, 2008). Also, the MFL department do many activities in their lessons to help Year 7 students remember vocabulary and presentations. There were no specific comments about WM activities being used in other departments with Year 8 students but a member of the RPE department reported using regular retrieval quizzes to support students' memory.

This is a confounding variable whose influence on the results seen in this study will be discussed further in the discussion and limitations section.

Table 139 shows over the two years that the vast majority of teaching staff have heard of Working Memory and that it can be linked to learning; this increases in the second year (100% in the first year and 98.5%). This pattern continues when the teaching staff are asked if they think developing WM has a positive impact on learning. In the first year the majority of 83.3% stated yes this increases to & 89.6% in the second year. In the first year 18.8 % of the teaching staff state they do think that the Science lesson structure to develop WM has the same impact as the normal way of teaching. This decreases to 11.1% in the second year. There is a shift to the negative response in the second year of 26.6%. This data is further clarified with the teaching staff responses to the statement “I think the science lesson structure to develop working memory has a positive impact on attainment compared to traditional teaching methods”. In the first year there is a positive response of 31.3%, becoming more positive in the second year with 44.8% stating yes. This is unexpected as the whole staff are aware that this is current research and warrants further discussion. The researcher bias and the Hawthorne effect may be occurring within these responses and this will be discussed within the discussion and limitations of the study later on in the thesis.