Investigating the Effects of Working Memory Capacity, Visual Spatial Ability and Attitudes on Academic Attainment in Secondary School Physics

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Abstract

The literature suggests that Academic Attainment (AA) in school science is strongly associated with two individual-level cognitive variables, Working Memory Capacity (WMC) and Visual Spatial Ability (VSA), and one individual-level affective variable, Attitudes towards Science (AS). However, few studies have applied a robust theoretical perspective to explain this association and even fewer have investigated the precise nature and strength of this influence on AA in physics in lower secondary education. My thesis bridges these gaps in the literature. Samples comprising 45 and 55 participants (aged 15 to 16) were obtained from two unrelated secondary schools in Bradford, a city in northern England. The participants' WMC and VSA were assessed quantitatively using the Digit Span Backwards Test (DSBT) and the Purdue Spatial Visualization Test of Rotations (PSVT: R) respectively. The participants' Attitudes towards Physics (AP) were gauged via questionnaire and two focus group interviews (one per school). The participants' GCSE grades in physics were used to represent AA in physics.

Multiple Regression Analysis (MRA) revealed statistically significant positive correlations between GCSE grades in physics and the aforesaid variables. These were as follows: VSA (PMCC =0.44); WMC (PMCC=0.33) and AP (PMCC=0.30). MRA also showed that collectively, these variables accounted for approximately 21% of the variance in GCSE grades in physics. In addition, analysis of the quantitative and qualitative data revealed six specific factors that strongly influenced the respondents' AP. These were as follows: perceptions of the physics teacher; self-efficacy in physics; perceptions of physics lessons; proficiency in mathematics; relevance of physics in the real world, and awareness of career opportunities related to physics. To explain these findings, I applied the theoretical perspectives afforded by Information Processing Theory (IPT) and Attitude Theory (AT). Using established criteria for assessing the probability of a causal relationship between variables, I argue that a direct causal link with AA is probable in the case of WMC and VSA, but the in the case of AP any causal link may be bidirectional.

There is strong empirical evidence in the literature to suggest that WMC and VSA can be improved through cognitive training. In addition, AT contends that attitudes towards any given phenomenon can be shifted in a more positive direction by manipulating the factors that strongly influence them. When viewed in the context of this literature, I argue that we can potentially improve GCSE grades in physics by targeting WMC, VSA and AP.

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Glossary

AA	Academic Attainment
ABC	Affective, Behavioural and Cognitive
AC	Alternating Current
ACP	Articulatory Control Process
ADHD	Attention Deficit and Hyperactivity Disorder
AE	Acoustic Encoding
ALSS	Attitude towards Learning of Science Scale
AP	Attitudes towards Physics
AQA	Assessment and Qualifications Alliance
AS	Attitudes towards Science
ASD	Autism Spectrum Disorder
ASE	Association of Science Education
AT	Attitude Theory
BERA	British Ethical Research Association
CDM	Cognitive Dissonance Model
CDT	Cognitive Dissonance Theory
CE	Central Executive
CI	Confidence Interval
CLS	Cognitive Learning Style
CLT	Cognitive Load Theory
CPU	Central Processing Unit
CST	Complex Span Test
DFE	Department for Education
DP	Decimal Place
DSBT	Digit Span Backwards Test
DSFT	Digit Span Forwards Test
EB	Episodic Buffer
ECL	Extraneous Cognitive Load
EM	Episodic Memory
ES	Effect Size

FE	Further Education
GCL	Germane Cognitive Load
GCSE	General Certificate of Secondary Education
HE	Hawthorne Effect
ICL	Intrinsic Cognitive Load
IM	Iconic Memory
IoP	Institute of Physics
IPT	Information Processing Theory
JCQ	Joint Council for Qualifications
KS4	Key Stage 4
LGA	Local Government Authority
LRA	Linear Regression Analysis
LSA	Learning Support Assistant
LTM	Long Term Memory
MRA	Multiple Regression Analysis
MRT	Mental Rotations Test
NAO	National Audit Office
NESE	National Examinations in Secondary Education
NC	National Curriculum
NN	Neural Network
OFQUAL	Office of Qualifications and Examinations Regulation
OFSTED	Office for Standards in Education
PD	Potential Difference
PF	Perception Filter
PL	Phonological Loop
PM	Procedural Memory
PMCC	Product Moment Correlation Coefficient
PS	Phonological Store
PSVT: R	Purdue Spatial Visualization Test of Rotations
SD	Standard Deviation
SDB	Social Desirability Bias
SE	Standard Error

SEN	Special Educational Needs
SF	Significant Figures
SM	Sensory Memory
SPSS	Statistical Package for the Social Sciences
SS	Spatial Subsystem
SSC	Secondary School Certificate
SSE	Standard Sampling Error
STEM	Science, Technology, Engineering and Mathematics
STM	Short Term Memory
TA	Thematic Analysis
TCM	Three Components Model
TORSA	Test of Science Related Attitudes
VE	Visual Encoding
VS	Visual Subsystem
VSA	Visual Spatial Ability
VSSP	Visual Spatial Sketchpad
WM	Working Memory
WMC	Working Memory Capacity
WMM	Working Memory Model

Chapter 1 Purpose of the Research

1.1 Introduction

My study addressed the following overarching research questions: Why do a significant number of students find physics academically challenging and what can be done to tackle this problem? I approached these questions by investigating the effects of two individual level cognitive variables and one individual level affective variable on Academic Attainment (AA) in physics at the secondary tier of education in England. The cognitive variables were Working Memory Capacity (WMC) and Visual spatial Ability (VSA), and the affective variable was Attitudes towards Physics (AP).

In addition, I applied two leading theories in the field of cognitive psychology, namely Information Processing Theory (IPT) and Cognitive Load Theory (CLT) in a novel way to potentially explain why these cognitive variables should influence AA in physics. I also applied Attitude Theory (AT), a dominant theory in social and educational psychology, to potentially account for the effects of the affective variable on AA in physics. In addition, I explored the individual level factors behind the development of AP. Post-positivism provided the overarching research paradigm that informed and guided my study. Specifically, my study: -

1. Investigated the nature and strength of the statistical association between GCSE grades in physics and VSA, WMC and AP respectively.

2. Applied the theoretical perspectives afforded by IPT and CLT to potentially explain why there should be a correlation between GCSE grades in physics and WMC and VSA respectively.
3. Applied the theoretical perspective afforded by AT to potentially explain why there should be a correlation between GCSE grades in physics and AP.
4. Explored the individual level factors that influence AP using mixed methods.

The primary data were collected from students (aged 15 to 16) attending two unrelated state-funded schools. Two randomized samples, comprising 45 and 55 students respectively were obtained, one from each school. The cognitive variables were measured numerically using two independent cognitive instruments. Specifically, VSA was measured by the Purdue Spatial Visualization Test of Rotations (PSVT: R) and WMC was measured by the Digit Span Backwards Test (DSBT). It was not possible to collect data on the participants' VSA from school-A (see Chapter 4, section 4.4 for a detailed explanation).

A questionnaire and two focus group interviews, comprising five students each, were used to gather quantitative and qualitative data on AP respectively. The questionnaire was designed by Hoyles et al., (2011) as part of a very large study to gauge AP of students (aged 15-16) attending secondary schools in England. Further details pertaining to the aforesaid measuring instruments are provided in Chapter 3.

1.2 Statement of the Problem

The field of educational psychology contains numerous studies reporting how a large proportion of students (aged 15 to 16) find physics academically difficult and challenging (Ekici, 2016; Francisco, 2010; Mulhall and Gunstone, 2008). Although many scholars and academics in the field agree that this is a major cause for concern in physics education, they appear divided over the primary agents responsible for these difficulties - the debate falls into two broad camps.

Many scholars contend that perceptions of physics play a prominent role in determining the extent to which students find physics academically challenging (Ahuja, 2017; Ekici, 2016; Barmby et al., 2008). They argue that students with broadly positive perceptions of physics are more likely to approach learning physics with enthusiasm and interest. These students will also tend to perceive challenges in physics as opportunities to further develop their understanding and knowledge (Erinosho, 2013; Ozel et al., 2013; Osborne and Dillon, 2008). In contrast, students who harbour chiefly negative perceptions of physics are more likely to find studying physics taxing and less rewarding. They will also tend to view challenges in physics as barriers to learning rather than as opportunities to gain a deeper understanding of the subject (Sahin and Yagabasan, 2012). Moreover, many researchers contend that negative perceptions of physics are strongly influenced by individual, classroom, parental and school level factors (Ozel et al., 2013; Francisco, 2010; Barmby et al., 2008).

Unpleasant learning experiences in the physics classroom can leave a lasting negative impression on the mind of the learner. Francisco, (2010) reports how physics lessons that students perceive as dull, uninspiring and difficult to follow tend to inculcate negative perceptions of physics and make the experience of learning physics off-putting. Oon et al., (2010) report that students who do not find physics lessons stimulating and engaging generally do less well in physics tests and examinations. In turn, a lack of academic success in physics can reinforce these negative perceptions. Francisco (2010) cites the lack of concrete incentives to motivate students to pursue their studies in physics as an important reason why many students find physics challenging. More especially, Francisco (2010) argues that poor levels of student awareness about careers in physics (and closely related fields) can make physics less appealing and promote the development of negative perceptions towards the subject. These negative perceptions can make physics appear more difficult and challenging for some students (Kaya and Boyuk, 2011; Stephen, 2010).

Others argue that students' perceptions of physics can be strongly influenced by their socio-economic background and the type of school they attend (Kaya and Boyuk, 2011; Stephen, 2010). Several studies report that students from affluent backgrounds attending private schools tend to be more favourably disposed towards physics and are more likely to obtain good grades in physics and continue studying the subject in the sixth form (Olasehinde and Ademola, 2014; Oon and Subramaniam, 2011).

However, very few studies have attempted to quantify the relationship between perceptions of physics and AA attainment in physics and even fewer have tried to explain why this relationship should exist in the first place from a theoretical perspective. My study bridged this perceived gap in knowledge and understanding. Specifically, I investigated the nature and strength of the correlation between Attitudes towards Physics (AP) and GCSE grades in physics. I then used AT to advance a post hoc explanation to potentially account for this correlation.

In contrast, other scholars argue that AP are less important than the content-driven nature of the physics curriculum, which they regard as a major reason why many students find secondary school physics difficult and challenging (Ekici, 2016; Redish, 1994). The main thrust of their argument is that the physics curriculum can place excessive demands on the cognitive capacity of many students (Angell et al., 2004; Byrne, 1994; Redish, 1994).

They argue that much of the physics content that students are expected to master at GCSE level relates to abstract ideas and concepts that are difficult to learn and understand (Mulhall and Gunstone, 2008; Mualem and Eylon, 2007). For example, Al-Ahmadi (2008) reports how topics related to mechanics and electromagnetism can be especially difficult for students to grasp. The aforesaid researcher attributes these difficulties largely to the fact that these forces of nature cannot be observed directly, only experienced through their effects.

Based on their literature review, Ornek et al., (2008) argue that the physics curriculum expects students to develop their understanding sequentially by building on previous ideas and concepts. This means that new information must be integrated with previous knowledge and understanding, placing a significant burden on the mental faculties of an individual. In addition, the physics component of the NC (which I shall refer to as the physics curriculum) requires students to mentally thread two or more concepts at the same time in order to develop learning (Al-Ahmadi, 2008; Ornek and Haugan, 2008). This can place further cognitive load on the mental faculties of the individual and make studying physics even more challenging (Norby and Peltoniemi, 2016; Al-Ahmadi, 2008; Ornek and Haughan, 2008).

To complicate matters further, ideas and concepts included in the physics curriculum are frequently crystallized and explained in the language of mathematics (Ogunleye, 2013; Oon, 2011; Ornek et al., 2008; Willington, 1983). This can add another layer of cognitive challenge when studying physics, especially for students who struggle in mathematics (Şahin and Yağbasan, 2012; Onwumere, 2009; Williams et al., 2003). For example, velocity-time and current-voltage graphs often feature in the physics curriculum at GCSE level and require a good understanding of mathematics to interpret and make sense of them (Onwumere, 2009; Al-Ahmadi, 2008). Moreover, the physics curriculum requires students to understand and apply upwards of 15 mathematical equations at GCSE level (DfE, 2015). Collectively, the concept-driven nature of the physics curriculum in tandem with the need to thread or sequence knowledge and concepts to develop understanding can place a heavy cognitive load on a student’s mental faculties. When we factor in the mathematical dimension, the cognitive burden can become very heavy and make studying physics very challenging.

To better understand the precise nature of the cognitive challenges involved in studying physics, I investigated the relationship between two cognitive variables, WMC and VSA on AA in physics respectively. As discussed in the next chapter, although the relationship between these two cognitive variables and AA in STEM subjects has been well documented, very few studies have specifically focused on physics and even fewer have tried to explain why the aforesaid relationship exists in the first place. My study bridges this perceived gap in knowledge and understanding. Specifically, I investigated the nature and strength of the correlation between WMC and VSA on GCSE grades in physics respectively. I then used IPT to advance a post hoc explanation to potentially account for this correlation. The specific research questions addressed in my study are given below: -

- What is the nature and strength of the correlation between GCSE grades in physics and Working Memory Capacity and Visual Spatial Ability respectively?
- What is the nature and strength of the correlation between GCSE grades in physics and Attitudes towards Physics?
- What kinds of factors strongly influence the development of Attitudes towards Physics?
- What is the nature and extent of the cognitive load imposed on Working Memory Capacity and Visual Spatial Ability by the National Curriculum when studying physics aged 15 to 16?
- How does Information Processing Theory explain the influence of Working Memory Capacity and Visual Spatial Ability respectively on GCSE grades in physics?
- How does Attitude Theory explain the influence of Attitudes towards Physics on GCSE grades in physics?

The next section explains why my research is important and necessary.

1.3 Social and Economic Importance of Physics

The fact that many students in England find physics academically difficult and challenging is concerning for two primary reasons (Ekici, 2016; JCQ, 2015; Aina, 2013). To begin with, modern society depends heavily on the products and services provided by physics. The latter underpins numerous technical disciplines such as telecommunications, civil engineering and computer science. Moreover, physics plays a key role in developing and improving a plethora of devices such as mobile phones, fridge freezers, washing machines, cars, microwaves, laptops, television and radio (Marusic and Slisko, 2012; Francisco, 2010). Physics also makes a significant contribution in other areas such as medicine and electrical power generation. Arguably, secondary school students need to gain a deeper appreciation of how modern societies benefit from technological advances rooted in physics. This argument echoes the key ideas proposed by Snow (1963) in his seminal work. Perceiving a cultural divide between those immersed in the fields of 'science' and 'the humanities' respectively, Snow (1963) argued that in order to advance human knowledge further and to benefit society even more, both parties should forge closer links.

The physics sector makes a sizable impression on the UK economy. For example, in 2012 (around the time when I began my research) physics accounted for 8.5% of the total economic output of the UK (IoP, 2015; 2012). It also directly employed over one million people and this number rises to 4 million when we include the supply and service chains that support it (Castell et al., 2014; IoP, 2014; 2012). The physics sector continues to expand as more companies enter this lucrative market (Dunn and Dreshler, 2016; IoP, 2014).

With the advent of the so-called ‘fourth industrial revolution’, the UK economy will become even more dependent on a highly skilled and technically literate workforce for continued growth and prosperity (Avis, 2019; Dunn and Dreshler, 2016; Whitlock, 2016). Physics is ideally suited to the task of equipping young people with many of the skills and competencies that will be needed in a more technologically driven economy (Archer et al., 2020; Osborne and Dillon, 2008). Indeed, as long ago as 1999, Goldstein came to the same conclusion when he wrote, ‘…a solid education in physics is the best conceivable preparation for the lifetime of rapid technological…change that…people expect to face’ (Goodstein, 1999:186). He clearly recognized the importance of physics in developing first-rate analytical, evaluative and logical thinking skills. He also understood how these skills and competencies could be applied across a wide range of domains that underpin the economy such as manufacturing, engineering and the financial sector. Moreover, the meteoric rise in telecommunications, personal computers and the internet means that a good education in physics is arguably even more important than that envisaged by Goodstein (1999). Indeed, a concrete education in physics can prove invaluable for anyone interested in pursuing a career in the aforesaid areas (Dunn and Dreshler, 2016; IoP, 2014).

Thus, given the importance of physics to society at large, it should be of concern to note that a significant number of students continue to struggle with physics and appear to shun post-16 physics largely for this reason (IoP, 2015; Aina, 2013; Kaya and Boyuk, 2011). For example, in 2015, about midway through my research, post-16 students in physics only accounted for about 4% of the entire cohort in England (JCQ, 2015). Worryingly, the situation has only marginally improved since then. In 2020, physics students only accounted for about 5% of the entire post-16 cohort in England (JCQ, 2020). Given that I carried out my research in England, it is important to understand the structure of the English education system, and this is discussed next.

1.4 Education in England

Education in England is regulated by the Department for Education (DfE). At the regional and local level, the DfE delegates Local Government Authorities (LGA) with the task of putting into practice education policy for state-funded schools. The latter are placed into two broad categories, namely comprehensive or grammar schools. Depending on funding arrangements, comprehensive schools are generally further subdivided into academies, free schools, those under the direct control of the LGA and others. However, regardless of their classification, all must submit to inspection and assessment by the Office for Standards in Education (Ofsted).

Education in England is currently divided into the following Key Stages: -

- Early Years Foundation Stage (aged 3 to 5)
- Primary Education (aged 5 to 11)
- Key Stage 1 Infants (aged 5 to 7)
- Key Stage 2 Juniors (aged 7 to 11)
- Secondary Education (aged 11 to 16)
    - Key Stage 3 (aged 11 to 14)
    - Key Stage 4
        - Year 10 (aged 14 to 15)
        - Year 11 (aged 15 to 16)
- Key Stage 5 or post-16 education (aged 16 to 18)
- Tertiary Education (aged 18 and above)

Normally, when students reach the end of Key Stage 4, they sit a series of examinations in different subjects for the General Certificate in Secondary Education or GCSE. At the time when this study was carried out, academic attainment in science (including physics) was graded in the following order of ascending merit: G, F, E, D, C, B, A, A* (JCQ, 2015). Given that education is compulsory until the age of 18 in England, those students who successfully negotiate Key Stage 4 (normally by achieving a grade C or better in five subjects including English and mathematics) proceed to post-

16 education. At this stage of the education cycle, students generally choose between following an academic route or a vocational route.

1.5 The National Curriculum

All government funded schools in England must follow the National Curriculum (NC). This comprehensive document provides a route map for education in England. It sets out: -

1. The subjects that are to be taught
2. The knowledge, skills and understanding required in each taught subject
3. The standard or attainment targets in each taught subject for every key stage
4. The assessment and reporting of pupil progress at each key stage

Certain subjects including English, mathematics and science are compulsory until the end of Key Stage 4 (KS4). Provided they adhere to the overall NC framework, state funded educational institutions have the freedom to design and tailor their teaching and learning approaches to meet the needs of their students more effectively (DfE, 2015).

1.5.1 The National Curriculum for Science

The National Curriculum (NC) for science lays down the central aims of science education at Key Stage 4 (KS4) as follows: -

- Develop scientific knowledge and conceptual understanding...'

- Develop understanding of the nature, processes and methods of science... to answer scientific questions about the world...'
- Develop and learn to apply observational, practical, modelling, enquiry, problem-solving skills and mathematical skills, both in the laboratory...and in other environments'
- Develop...ability to evaluate claims based on science through critical analysis of the methodology, evidence and conclusions, both qualitatively and quantitatively.

(Adapted from DfE, 2015:3-4)

In addition to reflecting these core aims, the physics component of the NC, namely the physics curriculum expands and develops knowledge and understanding in the following areas at KS4: -

- Work, Energy, Power and Thermodynamics
- Particle Model of Matter
- Atomic Structure and Radioactivity
- Electricity, Magnetism and Electromagnetism
- Mechanics (including forces and motion)
- Mechanical and Electromagnetic Waves
- Space Physics

(Adapted from DfE, 2015:31-33)

In providing an overarching conceptual framework and establishing the content that needs to be covered, the physics curriculum sets the level of academic rigour which students at KS4 are expected to reach (normally at grade C or better). The cognitive load arising from the physics curriculum and its impact on the cognitive-affective variables is discussed more fully in Chapter 6. The next section provides a detailed outline of the structure and organization of my research.

1.6 Layout of the Study

My dissertation is made up of 8 further chapters as follows: Literature Review (two parts); Research Methodology and Methods (three parts); Searching for Correlation; Information Processing Theory; Explaining the Correlation; Analysis of Attitudes towards Physics (two parts); Attitude Theory; Conclusion and Suggestions for Further Research.
Chapter 2 surveys the published literature in my field of interest; it is divided into two parts or sections. The first part focuses on the two independent level cognitive variables, namely WMC and VSA. The second part spotlights the independent level affective variable AP. Prevailing ideas and theories in the literature are used to define and contextualize the parameters under investigation in each part.

In addition, the literature is critically examined and perceived gaps in knowledge and understanding are identified in each section. Importantly, contested issues and disagreements in the literature are evaluated in each section, especially in terms of their impact on the outcomes from this study. Moreover, the original contribution my research makes in moving the field forward is explicitly outlined in each part.

Chapter 3 justifies and explains the research methodology and methods used to achieve my goals. It is divided into three major parts or sections. Part I introduces the central tenets of the post positivist paradigm that framed my study from start to finish. In particular, the chapter explains how the epistemological and ontological precepts of this paradigm influenced the study. The reasons for embedding the research in this specific paradigm are also discussed in some depth. This section also explains why I chose to combine inductive and deductive dimensions in my research. It also includes a detailed discussion on the potential impact of positionality and reflexivity on the research process. Part II breaks down the ensuing research design into the following broad headings: integrity and validity in research; testing hypotheses; making a prediction; statistical and thematic analysis; causality; inductive and deductive reasoning; sample selection; sample bias and the role of ethics in research.

Part III focuses on the data collection instruments that were used to measure the aforesaid variables. As well as discussing their strengths and weaknesses, this section also explains why these instruments were selected in the first place.

It also highlights how the lessons learned from piloting these instruments informed the principal data collection phase. Brief profiles of the two schools that took part in the study are also included in this chapter.

Chapter 4 begins with a short review of the overall statistical approach used in this study. It then reveals the outcomes from the statistical analysis of the quantitative data obtained from the two cognitive tests. The latter were used to assess the WMC and VSA of the participants in the study. In particular, the chapter focuses on the following outcomes: Mean and Standard Deviation (SD) of the aforesaid variables and their statistical significance; rejection of the null hypotheses in favour of the alternative hypotheses (if warranted); strength of linear correlation between the individual level cognitive variables and GCSE grades in physics respectively and Multiple Regression Analysis (MRA). Moreover, the chapter critically reflects on the implications of these findings on improving overall attainment in secondary school physics.

Chapter 5 introduces Information Processing Theory (IPT) and its derivative the Working Memory Model (WMM). The chapter begins by explaining the central tenets of IPT; it then breaks down the theory into its constituent elements and explains each of these in turn. The chapter then spotlights the WMM; after explaining the core principles that underpin the model, the chapter breaks down the model into its constituent components and explains each of these in turn. It then employs the theoretical perspectives afforded by the WMM to explain the critical role Working Memory Capacity (WMC) and Visual Spatial Ability (VSA) play in the learning or sense making process.

The chapter then discusses contested issues and perceived weaknesses associated with IPT and its derivative the WMM. It then critically examines the extent to which these contested issues and perceived weaknesses undermine these theories; particularly in terms of explaining the critical role that WMC and VSA play in the learning or sense making process.

Chapter 6 employs IPT and the WMM to explain why there should be a positive linear correlation between GCSE grades in physics and WMC and VSA respectively. In addition, the chapter employs Cognitive Load Theory (CLT) to explain why possessing a large WMC and good VSA can be especially beneficial when studying physics. In addition, CLT is used to explain the adverse effects on learning physics if the cognitive load exceeds the WMC and VSA of the individual. The chapter then discusses how 'stakeholders' such as physics teachers and curriculum planners can potentially reduce cognitive load. The chapter also reflects on the extent to which contested ideas and perceived weaknesses in CLT undermine its ability to explain why having a large WMC and good VSA can be advantageous when studying physics.

Chapter 7 reveals the outcomes from the statistical analysis of the quantitative data obtained from the attitude questionnaires. This data was used to assess the participants AP. After identifying the mean and SD related to AP, the chapter reveals the nature and strength of the correlation between AP and GCSE grades in physics and discusses the implication of this correlation on improving overall AA in physics. The chapter also reveals the findings from Multiple Regression Analysis (MRA) and discusses their implications on AA in physics. It also reflects on the possibility of a causal relationship between AA in physics and the cognitive-affective variables (respectively) and the potential direction of causality. In addition, employing aspects of statistical and thematic analysis, the chapter identifies the key factors that influence AP. Wherever possible, wider perspectives from the published literature relating to these factors are also included in the discussion. Also, the chapter reflects on the possibility of manipulating these factors to promote the development of more positive AP.

Chapter 8 explains the nature of attitudes through the theoretical prism afforded by AT, a leading theory in social and educational psychology. The latter is also used to explain why there should be a robust link between AP and GCSE grades in physics. In addition, the chapter evaluates the extent to which contested ideas and controversies surrounding AT undermine its ability to define and explain the nature of attitudes and account for the relationship between the aforesaid variables.

Chapter 9 provides a concise summary of the research from its conception to its completion. It begins by restating the problem along with the corresponding aims and then explains how these were met. It then summarizes the key features of the research as follows: overarching research paradigm; research methodology and methods; establishing the original contribution; discussing the strengths and weaknesses of the research and identifying areas for further research. In addition, the chapter discusses the level of confidence associated with each research finding. Personal reflections on the overall research journey are also included in this chapter.

1.7 Conclusion

Several studies report that many students find physics academically challenging and arguably show little interest in post-16 physics largely for this reason. This is a major cause for concern given how physics underpins multiple technical disciplines and makes a sizable contribution to the UK economy. Moreover, arguably physics education is ideally suited for equipping the next generation with the technical skills and proficiencies needed to prosper in the digital age. Interestingly, although these studies identify the problem, they appear to have little to say when it comes to explaining why so many students struggle with physics in the first place and what can be done to remedy this situation. My study bridges this perceived gap in knowledge using a fourfold approach.

Firstly, it investigated whether there is a significant correlation between two cognitive variables (WMC and VSA) and the one affective variable (AP) with GCSE grades in physics respectively. These variables are known to affect both attainment and interest in science, engineering and mathematics subjects. Secondly, the study used the theoretical perspectives afforded by IPT, CLT and AT to explain why there ought to be a link between the aforesaid variables and attainment in physics. Thirdly, my study identified the key factors behind the development of AP via statistical and thematic analysis. It then explored the possibility, from the standpoint of AT, whether these factors could be manipulated to promote the development of more positive AP. Finally, my study explored the possibility of raising academic standards in physics by specifically targeting the aforesaid cognitive-affective variables. It is anticipated that the outcomes from my study will be of interest to key stakeholders in physics education and the wider research community in the field of educational psychology.

Chapter 2 Literature Review (Part I)

2.1.1 Introduction

This chapter comprises two parts or sections; part I begins by restating the research problem and the overall aims arising from it. The central tenets of cognitive psychology are then presented in order to explain and contextualize the individual level cognitive variables WMC and VSA. The chapter then spotlights the controversy surrounding the nature of the aforesaid variables and discusses the implications of this controversy on the present study. In addition, the chapter critically reviews the literature pointing to a positive correlation between the aforesaid variables and AA in STEM subjects. Focusing on physics, the chapter then discusses the possibility of improving AA in STEM subjects by enhancing WMC and VSA through cognitive or mental training. The chapter also explains how the hypothetical construct AA was conceptualized and then operationalized in the current context.

2.1.2 Research Aims and Relationship to Literature Review (Part I)

I investigated why a significant number of students in secondary education find physics academically challenging. I addressed this problem by drawing on learning theories from the fields of cognitive and social psychology, specifically IPT and AT. I also reviewed the published literature in both fields to find out what was already known about the problem. This revealed that the influence of WMC, VSA and Attitudes on AA in STEM subjects has been well documented. However, few studies have quantified the strength of this influence on GCSE grades in physics and even fewer have used IPT and AT to explain why this influence exists in the first place. My study bridges the gap in the literature on both counts.

2.1.3 Overview of Cognitive Psychology

At the fundamental level, cognitive psychologists propose that the human brain can be regarded as the biological equivalent of a complex and sophisticated computer (Weisberg and Reeves, 2013; Baddeley, 2012; Miller, 2011). They contend that the way the brain processes or makes sense of auditory, visual spatial and kinaesthetic information is comparable to the way in which a computer processes electronic information. Thus, they hold the '…view that human cognition can be understood by comparing it with the functions of a digital computer' (Gross, 2012:40).

They also contend that mental processes are real in the sense that they can be studied scientifically. Thus, we can apply logic and reason to develop testable theories with predictive powers to explain cognitive processes (Cowan, 2014; Eysenck and Keane, 2010; Al-Enezi, 2008).

Cognitive psychologists further contend that whenever we engage in learning, we place a certain amount of cognitive load on our mental faculties (Jalani and Sern, 2013). They break down this mental load into three principal types. The first relates to Intrinsic Cognitive Load (ICL) and represents the inherent complexity of the material that we are trying to learn or competency that we are trying to master. The magnitude of ICL is strongly influenced by our previous exposure to the material that we are trying to make sense of (or process). The second relates to Extraneous Cognitive Load (ECL) and equates to processing information that does little to progress learning. In effect, ECL represents wasted mental effort and appears to relate strongly to the way in which the learning material is presented. Germane Cognitive Load (GCL) represents the third dimension of cognitive load. This is associated with the development of individual level learning frames or mental schemas that help make learning more effective (Hinojosa, 2015; Jalani and Sern, 2013). Learning frames can be constructed independently by the learner or with support from the teacher for example. Importantly, cognitive psychologists contend that learning can become seriously impaired if the total cognitive load (ICL, ECL and GCL) exceeds the mental processing capacity of the individual (Jaeger et al., 2017; Hindal et al., 2013; Baddeley, 2012).

Critics of cognitive psychology fall into four broad groups. Firstly, some argue that cognitive psychologists largely ignore the influence of affective factors in the learning process (Jalani and Sern, 2013; Taylor, 2013). Secondly, by arguing that we all process information in the same way, cognitive psychologists appear to disregard individual differences that might influence the information processing cycle (Taylor, 2013; Baddeley, 2012). For example, some individuals can become easily distracted and lose their focus while others can maintain their concentration for much longer, even in a noisy environment. Thirdly, much of the research in cognitive psychology has been carried out in laboratories or by using mathematical models (Cowan, 2014; Baddeley, 2012). Critics argue that the real world is messier, and complex compared to the sanitized conditions found in a laboratory or in mathematical models. On that basis they question the validity and reliability of the claims made by cognitive psychologists in this area (Hinojosa, 2015; Jalani and Sern, 2013).

Another major criticism is that the three types of cognitive load may not be as sharply defined as advocated by cognitive psychologists. Critics argue that they may overlap, and this can make them more complicated and difficult to understand. For example, the point at which ICL ends and GCL begins is keenly contested by many scholars and academics in this field (Nemes, 2011). Notwithstanding these criticisms, cognitive psychology maintains a prominent position in social and educational psychology (Jaeger et al., 2017; Baddeley, 2010). We can now use this overview of cognitive psychology to briefly explain the core attributes of WMC and VSA. A more detailed discussion of these cognitive variables and the two theories, (IPT and CLT) that I used in a novel way to investigate their relationship with AA in physics is provided in Chapters 5 and 6.

2.1.4 Working Memory Capacity (WMC)

The individual level cognitive factor WMC represents the mental faculty where '…planning, comprehension, reasoning and problem solving…' takes place (Cowan, 2014:197). Incoming information, auditory, visual spatial and kinesthetic is temporarily held and processed inside our WMC (Baddeley, 2012; Nemes, 2011; Hindal and Reid, 2009). The volume and complexity of the information that can be processed at any given time depends on the size of the WMC and this varies between people (Alloway, 2014; Baddeley, 2010). This means that an individual with a greater WMC can process relatively more complicated and voluminous information compared to someone with a more limited WMC. Thus, possessing a greater WMC can be advantageous when it comes to learning and understanding (Alloway, 2014; Schraw and McCrudden, 2013). The learning benefits afforded by having a larger WMC when studying physics are discussed in Chapters 5 and 6.

2.1.5 Visual Spatial Ability (VSA)

The individual level cognitive factor VSA relates specifically to the processing of visual spatial information (Maeda and Yoon, 2013; Uttal and Cohen, 2012). We can perhaps better appreciate the central attributes of this mental faculty through an example. Imagine a six-sided dice numbered 1 to 6. Rotate the dice slowly in your mind and read the number on each face as it comes into view. Now introduce another dice and repeat the exercise. To make it more challenging, add, subtract and multiply the two numbers as they come into focus. The mental dexterity with which you can rotate the die in your mind, coupled with how well you can carry out the arithmetic operations reflects your visual spatial processing abilities or VSA. Kelly (2012) encapsulates these core features of VSA concisely as follows: -

> 'Students' spatial ability skills are based on their capability to mentally understand, visualize, and manipulate two-dimensional and three-dimensional objects or their pictorial representation' (Kelly, 2012:268).

Several studies have suggested that individuals possessing strong VSA can visualize abstract ideas and concepts more clearly and process information presented in graphical form or as a schematic diagram more efficiently (Maeda and Yoon, 2016; 2013). They can also manipulate formulae effectively and recognise the relationship between the variables in these formulae relatively easily (Kelly, 2012; Uttal and Cohen, 2012). The potential advantages afforded by possessing good VSA when studying physics are discussed in Chapters 5 and 6 from the standpoint of IPT and CLT. Cognitive psychologists regard VSA as an integral component of the broader cognitive architecture comprising WMC (Cowan, 2014; Baddeley, 2010). Thus, the VSA dimension often features in conversations regarding the precise nature of WMC (Baddeley et al., 2014; Oztekinet al., 2008; Geake, 2006). This dimension is addressed more fully in Chapter 5. The next section spotlights a major controversy in the field of cognitive psychology related to WMC.

2.1.6 Contested issues related to WMC and VSA

The literature review reveals two contrasting views about the nature of WMC and VSA. Some scholars contend that the aforesaid variables are largely influenced by genetic factors and reach their maximum extent in early adolescence (Sorqvist et al., 2013; Shipstead et al., 2012; Woehrl and Magliano, 2012; Miller, 1956). The idea that WMC and VSA are chiefly determined by our genes and become fixed and stable after a certain age largely stems from the work of Miller (1956) who is regarded as one of the founders of cognitive psychology (Weisberg and Reeves, 2013; Cowan, 2010, 2014). Studies that appear to support this view have emerged periodically over the years (Melby-Lervag et al., 2016; Shipstead et al., 2012; Choo et al., 2012). However, in the past few decades this view has been challenged by many scholars who argue that there is now substantial evidence to suggest that WMC and VSA are strongly influenced by environmental factors and are more flexible and dynamic than previously believed (Deveau, 2015; Allen et al., 2014; Klingberg, 2014; Harrison et al., 2013; Enriquez-Ceppert et al., 2013).

Both parties agree that there is considerable variation in WMC (and its visual spatial component, namely VSA) in the general population. However, the proportion of variance in WMC and VSA that can be accounted for either by genetic or environmental factors remains largely unclear (Cowan, 2010; Holmes and Adams, 2006). Given that I investigated the correlation between WMC and VSA with AA in physics respectively, both views have important implications for my research.

Establishing a positive correlation between these cognitive variables and AA in physics would lose some of its potency if it transpired that these variables were relatively stable and enduring. It would remove the possibility of improving AA in physics by targeting these variables through some form of intervention. Alternatively, if it emerged that these variables were influenced by environmental factors and were relatively flexible and dynamic, it would open the possibility of improving overall AA in physics by targeting them through intervention. As we shall see, the view that WMC and VSA are strongly influenced by environmental factors and have a flexible and dynamic nature has arguably gained supremacy in the debate.

2.1.6.1 Improving WMC and VSA through Mental Training

Studies suggesting that WMC and VSA respond well to mental training are growing rapidly (Alloway, 2014, 2012; Harrison et al., 2013). This expansion is noted by Morrison and Chen (2011) as follows: ‘A growing body of literature shows that one's working memory (WM) capacity can be expanded through targeted training’ (Morrison and Chen, 2011:46). For example, as part of a wider piece of research, McNab et al (2009) carried out a study in Stockholm, Sweden in which a group of young people were subjected to computer-based mental training for 35 minutes every day over a period of five weeks. Shortly after completing the mental training, their WMC and VSA was tested, and an overall improvement was noted. A particular strength of their study is that the approach they used has been frequently employed by other researchers when investigating the effects of targeted intervention on some parameter or variable. McNab et al (2009) tested the WMC and VSA of the participants beforehand, administered the mental training, then assessed their WMC and VSA exactly as before and found a measurable overall improvement. A limitation of their research is that they do not say whether the overall improvement in WMC and VSA was short- or long-lived. Their central finding which suggests that WMC and VSA can be improved through mental training chimes with those reported in other studies (Brudigam and Crawford, 2012; Klemm, 2012; Elliot et al., 2010; Smith et al., 2009).

Alloway et al., (2012) also investigated the effects of computer-based mental training in improving WMC and VSA. In a series of clinical trials, participants were placed into three separate categories as follows: non-active control group (63 students), low-active training group (51 students) and high-active training group (34 students). The WMC and VSA of all three groups were assessed in addition to other cognitive parameters (IQ for example). The students in the non-active control group received no mental training, those in the low-active group received mental training once a week and those in the high-active group received mental training four times a week.

The WMC and VSA of all three groups were then retested immediately after the computer-based mental training programme had ended and eight months later. Alloway et al., (2012) found that students in the high-active training group showed the biggest overall improvement in WMC and VSA scores. Those in the low-active training group also showed an overall improvement in their WMC and VSA scores but not to the same extent as those in the high-active training group. The WMC and VSA scores of those in the non-active training group remained constant (within the bounds of experimental error).

Crucially, the relative improvement in the WMC and VSA of the students in the groups that had received the computer-based mental training were broadly present eight months later when they were tested again. This suggests that an overall improvement in WMC and VSA arising from computer-based mental training may be relatively permanent and enduring. However, the Alloway et al., (2012) study is comparatively isolated and the outcomes from this study need to be confirmed by other studies in this field. A review of the literature in 2021 suggests that the issue regarding the longevity of the overall gains in WMC and VSA made through computer-based mental training remains largely unresolved.

A particular strength of the Alloway et al (2012) study is that the non-active control group (which received no intervention) provided a baseline against which the effects of the intervention could be compared. Moreover, their study suggesting that WMC and VSA can be improved through computer-based mental training broadly chimes with other studies (Lauer et al., 2015; Cherney et al., 2014; Sorby et al., 2013; Moe, 2012). In the intervening years since the Alloway et al (2012) study, there has been a sharp increase in the number of commercially available software packages that claim to help improve WMC and related cognitive functions; examples include MindSparke and Cogmed.

Klemm (2012) neatly summarizes the growing body of evidence suggesting that WMC is strongly influenced by environmental factors and can be enhanced or expanded through appropriate mental training, '...we have so many published reports that working memory capacity can indeed be expanded by training' (Klemm, 2012:16). With respect to VSA, Uttal and Cohen (2012) conclude that '...substantial research has established that spatial skills are malleable - that they respond positively to training...' (Uttal and Cohen, 2012:148). Both Klemm (2012) and Uttal and Cohen (2012) reach their respective conclusions after carefully reviewing studies featured in credible peer-reviewed journals.

However, some cognitive psychologists remain unconvinced and offer an alternative explanation to account for the improvement in WMC and VSA after mental training. They argue that mental training may simply allow us to use our existing WMC and VSA more efficiently and effectively (Melby-Lervag, 2013; Shipstead, 2012). In effect, '…mental training……develops a specific skill…to more efficiently process...information' (Weisberg and Reeves 2013:49). A literature review carried out in 2021 showed that these opposing views were still being keenly debated in the field of cognitive psychology.

Arguably, support for the contention that WMC and VSA can be expanded through mental training comes from the relatively new discipline of neuropsychology. Several studies in this field report that mental training produces a measurable rise in neural activity in the regions of the brain where cognitive processes linked to WMC and VSA are said to take place (Allen, et al., 2014; Woolfolk, 2014; Prendergast, et al., 2013). Moreover, evidence suggesting that these changes are relatively enduring is growing, especially if mental training is undertaken regularly (Klingberg, 2014; D'Ardenne et al., 2012; Geake, 2008; Oztekin et al., 2008).

To account for the physiological changes in the brain, these studies suggest that mental training strengthens and reinforces existing neural pathways as well as creating new neural pathways in the regions of the brain associated with WMC and VSA (Deveaux et al., 2015; Klingberg 2014, 2009; Enriquez-Ceppert et al., 2013). Indeed, Klingberg (2014) who has published extensively in this field carried out a comprehensive review of the literature and concluded that it may be possible to enhance WMC by as much as 20%, "...targeted mental training…most research shows an improvement of roughly 15-20%" (Klingberg, 2014: Online Lecture, Improving Working Memory Capacity).

Arguably, evidence suggesting that WMC and VSA are flexible and dynamic and respond well to mental training is mounting. This has important implications for my research, not least given that I found a positive linear correlation between GCSE grades in physics and WMC and VSA respectively (see Chapter 4). When viewed alongside each other, they suggest that we can improve overall GCSE grades in physics by targeting WMC and VSA via mental training. This possibility further enhances my contribution to knowledge and understanding in this field.

2.1.6.2 Main Focus of the Literature

A review of the published literature reveals that most studies appear to focus on investigating the effects of WMC and VSA on AA in STEM subjects (Cherney et al., 2014; Foster et al., 2014; Sorby et al., 2013; Moe, 2012). Moreover, the studies that focus on science almost invariably view it as a single subject rather than as comprising three separate disciplines namely chemistry, biology and physics, each with its own unique identity and scientific tradition. This is potentially problematic because the outcomes from these studies are generally assumed to apply equally across all three scientific disciplines and this may not always be the case (Erinosho, 2013; Cakici et al., 2011). For example, a student might have a deeper understanding of chemistry compared to biology and physics simply because the cognitive demands on WMC and VSA are different. Consequently, the student might do better in the chemistry component of the science examination. However, this aspect may not be reflected in the overall science grade since the latter is normally determined by aggregating scores from all three subjects. Thus, differences in AA between physics, chemistry and biology may not always get picked up when science is viewed holistically (Gill and Bell, 2011; Barmby and Defty, 2008, 2006; Kuenzi, 2008).

In England the reason why science appears to attract more attention from researchers might relate to the fact that the bulk of secondary schools enter their students for the GCSE in science rather than physics, chemistry and biology separately (JCQ, 2015). Another reason may relate to the funding dimension; for example, in 2017 a newsletter issued by an organization that provides information and advice regarding postgraduate research opportunities in the UK reported that '…an additional 1,000 PhD scholarships have been announced for STEM subjects' (newsletter@findaphd.com, 2017).

In addition, some academics argue that science should be viewed holistically rather than as discrete units or components (Erinosho, 2013). These reasons may partly explain why the numbers of studies investigating the relationship between AA in science and WMC and VSA are more numerous compared to those investigating the relationship between these variables and AA in physics. It is important to understand what these studies have to say as this will assist in contextualizing the findings from the very few studies that have investigated the relationship between these variables and AA in physics.

2.1.7 Relationship between WMC, VSA and AA in STEM

Numerous studies report a robust link between WMC and VSA with AA in STEM subjects (Foster et al., 2015; Finn et al., 2014; Crossland, 2010; Jung and Reid, 2009). For example, Ali and Reid (2012) investigated, amongst other aspects, the relationship between WMC and AA in mathematics of students attending two schools in the city of Lahore in Pakistan. They used two relatively large samples, 456 from the first school and 357 from the second school. After carefully analysing the quantitative data, they concluded that '… working memory capacity has a very strong influence on performance in mathematics…' (Ali and Reid 2012:283).

A potential weakness of their study is that they had to translate the 'testing material' (used to assess WMC) from English into Urdu because the schools involved in their study taught predominantly either in English or in Urdu.

Translating materials between languages can introduce subtle changes in meaning and interpretation and these can undermine confidence in the outcomes (Zavala-Rojas, 2014). Their central finding showing that AA in mathematics is strongly influenced by WMC closely mirrors findings from other studies pointing to a robust relationship between WMC and AA in STEM subjects (Chuderski, 2012; Best et al., 2011).

In another study, Maeda and Yoon (2015) investigated the relationship between VSA and AA of first year undergraduate students studying STEM subjects and found a moderate to strong correlation between them. They used a large sample, comprising 2,500 students obtained via randomized sampling. A potential weakness of their study is that they view science as a single subject. This is increasingly being called into question on the grounds that this approach largely ignores the unique challenges to learning presented by each scientific discipline, namely chemistry, biology and physics (Erinosho, 2013; Cakici et al., 2011).

Nevertheless, their central finding resonates with other studies reporting a strong relationship between VSA with AA in STEM subjects (Hegarty, 2014; Wang, 2014; Holly et al, 2013; Reid, 2009b). To add further weight to their principal finding, Maeda and Yoon (2015) carried out their own detailed review of the literature and concluded that: -

> 'Studies dealing with spatial ability have accumulated evidence to support a positive link between the ability and performance... particularly in the fields of science, technology, engineering and mathematics...' (Maeda and Yoon, 2013:70).

A major weakness of both studies is that they are largely descriptive and provide little in the way of a sustained and coherent theoretical argument to account for the robust relationship between AA in STEM subjects and WMC and VSA uncovered by their respective investigations. Moreover, these weaknesses reflect the broader deficiency in the wider literature.

With respect to secondary school physics, the literature is largely silent. Of the very few studies carried out in this area, most focus on investigating the relationship between WMC and the ability to solve problems in physics (Chen and Whitehead, 2009; Ogunleye, 2009). For example, Johnstone et al., (1993) reported finding a positive correlation between WMC and the ability of students to solve problems in secondary school physics. Chen and Whitehead (2009) also investigated the relationship between solving problems in physics and the WMC of students (aged 13-15) in Taiwan. They concluded that, 'Those with higher working memory capacities were found consistently to understand the ideas of physics better' (Chen and Whitehead, 2009:151). I developed and extended the relatively sparse body of knowledge in this field in two specific ways. Firstly, I established the precise nature and strength of the influence of WMC and VSA on AA in secondary school physics. Secondly, I used IPT to advance a post hoc explanation to potentially account for this correlation.

2.1.8 Academic Attainment (AA)

Academic Attainment, (AA) is a complex and multifaceted hypothetical construct that encompasses myriad educational outcomes; this makes it extremely difficult to define (Spinath, 2012; Hattie, 2009; Woolfolk, 2007). Arguably, Sadler, (1987) captures the essence of AA as follows: -

> '…a definite level of excellence or attainment, or a definite degree of any quality viewed as a prescribed object of endeavour or as the recognized measure of what is adequate for some purpose, so established by authority, custom, or consensus' (Sadler, 1987:194).

From this standpoint, AA is largely determined by the criteria we use to measure it. These criteria represent learning standards against which AA can be decided or judged. Chief amongst these is the curricular-based standardized summative assessments. Spinath, (2012) argues that a summative assessment represents any appropriate method of evaluating learning and understanding at the end of a prescribed period of study using standardized learning criteria. In the English education system, the GCSE represents a prime example of the criteria driven, standardized summative assessment (Spinath, 2012; Woolfolk, 2007; Hattie, 2009). Introduced in England over 30 years ago, the GCSE provides formal certification of AA at the lower tier of secondary education. Typically, students (aged 16) take GCSE examinations at the end of a two-year course of study at Key Stage 4 (see Chapter 1). AA is then operationalized using the grading structure; in particular, the latter employs standardized learning criteria or learning standards to assess AA.

The standardized learning criteria function as anchor points or benchmarks against which we can assess AA. They represent negotiated understandings of what counts as AA and shared conventions of how to judge the aforesaid hypothetical construct. At the GCSE level of education, we can translate these judgments into common currency using a calibrated grading scale (see Chapter 1). Thus, the GCSE grade is awarded by comparing the quality, breadth and depth of learning and understanding (demonstrated by the learner in the summative assessments) with the relevant standardized learning criteria and classifying it accordingly. For example, the GCSE grades in physics of the participants in my study reflect AA based on the following broad learning standards: Demonstrate Knowledge and Understanding ~40%; Apply Knowledge and Understanding ~40%: Analyse Information and Ideas ~20% (AQA, 2015).

The literature review suggests that the GCSE grade is generally recognized as a symbolic representation of AA by those involved in the formal education system (Spinath, 2012; Woolfolk, 2007). Moreover, the GCSE qualification and its grading structure are overseen by the government appointed regulator Ofqual. This organisation is largely responsible for ensuring parity between the different awarding bodies and for maintaining the value and standing of the GCSE qualification over time (Ofqual, 2021).

2.1.8.1 Challenges to Grade Integrity

The integrity and fairness of the GCSE grading system in assessing AA has been questioned for many years by a wide variety of people, not least those involved in delivering and assessing secondary education. In the context of the present study, integrity represents the extent to which what is being graded genuinely qualifies as AA and is not something else (Mihaela, 2012; Newton, 2007). Fairness represents the extent to which the assessment process is impartial, non-discriminatory and does not favour one individual or group above another (Mihaela, 2012; Newton, 2007).

The literature review suggests that criticisms related to integrity and fairness fall into six broad areas. Many argue that instead of representing the quality, scope and depth of learning and understanding, the GCSE grade largely reflects how adept an individual is at getting a good grade. They argue that formal education is a process, and some individuals are more tuned into this process than others. These individuals realize what is expected of them and they go about getting it done; learning and understanding is not a primary consideration for these individuals. For example, several studies have reported that well organized and self-disciplined individuals with good time-management skills tend to attain higher grades (Baird et al., 2017; Newton, 2007).

Another major criticism of grades at GCSE level is that they do not consider progress and development in other areas. For example, they ignore improvements in attendance, effort, participation and personal resilience; many argue that these factors play an important role in developing a well-rounded individual (Stobart and Eggan, 2012; Newton, 2007). Although these criticisms add fuel to the broader discussion regarding what counts as AA, they do not impinge directly on my study.

A further criticism of GCSE grades is that they do not consider the physiological and psychological condition or state of the individual taking the formal examination (Mihaela, 2015; Putwain, 2009). For example, an individual may have a deep understanding of fundamental concepts in physics but cannot demonstrate this understanding in a formal examination because of mental distress or physical illness (Mihaela, 2015; Putwain, 2009). However, advocates of the current education system largely dismiss these claims. They argue that the GCSE grade is based on an aggregate score which will reduce or ‘smooth out’ these effects (William, 2010; James, 2008). In addition, they argue that anyone unable to take the GCSE examination (on sound medical grounds) can defer the examination. In some cases, the individual may even be awarded the GCSE grade predicted by their teachers. The predicted grade is frequently based on formative assessments and internal summative assessments undertaken throughout the duration of the course.

Critics also contend that GCSE grades are strongly influenced by socio-economic factors. For example, it has been well documented that offspring of well-educated or affluent parents tend to achieve higher grades (Stobart and Eggen, 2012; Sammons, 1995). In addition, critics argue that gender plays an important part in determining GCSE grades. For example, figures released by the DfE (2019) show that on average ~67% of females achieved a grade 4 (or better) across the broad spectrum of subjects at GCSE level compared to ~61% of males in England (DfE, 2019). Critics point out that despite influencing GCSE grades, socio-economic factors and gender are not included in the GCSE grading structure. They argue that precluding these factors undermines the integrity and fairness of the GCSE grade when assessing AA.

Critics also argue that GCSE grades do not necessarily represent a linear function of AA. This is because they are based on aggregate scores that tend to cluster round the centre of the grading scale or the midpoint of the range (Ofqual, 2019). However, I have assumed that GCSE grades represent a broadly linear function of AA. My position falls broadly in-line with most academics involved in educational research (Childs and Baird, 2020; Williams, 2010). However, a future study could investigate the appropriateness of this assumption.

Despite these criticisms, the government remains committed to the current GCSE examination system for assessing AA at KS4. Moreover, the literature review suggests that the majority view of those involved in formal education is that the current GCSE grading structure provides a broadly fair, balanced and accurate assessment of varying levels of AA (Childs and Baird, 2020; Williams, 2010). I have also adopted this overall position or stance; however, as discussed above I am aware that this position has certain limitations.

2.1.9 Conclusion

Part I of the literature review has outlined the central tenets of cognitive psychology. It introduced the individual level cognitive variables WMC and VSA. It then spotlighted the current debate amongst educational psychologists regarding the fundamental nature of the aforesaid variables. Some argue that environmental factors largely determine their core nature while others favour genetic factors. The literature review suggests that environmental factors may exert the stronger influence. The chapter then reviewed the literature pointing to a positive correlation between AA in STEM subjects and the aforesaid variables respectively. Measures that could potentially enhance or improve WMC and VSA were then discussed, especially those related to mental training. The chapter also explained how the hypothetical construct AA was conceptualized and then measured via GCSE grades in physics.

2.2.1 Literature Review (Part II)

Part II reviews the literature pertaining to the concept of attitudes. It begins with a brief overview of the research aims that made this review necessary. It then explains the core attributes of attitudes as understood by most scholars and academics in the field of social and educational psychology. The chapter then discusses what is already known about the relationship between Attitudes towards Physics (AP) and Academic Attainment (AA) in physics. In addition, perceived gaps in knowledge and understanding are identified and followed by a discussion of how my study addressed them. When reviewing the literature, AA was deemed to represent an individual's grade, level or score in summative assessments of any kind either in physics or subjects closely related to physics, namely STEM. However, with respect to my study, AA represents the GCSE grade in physics achieved by a student in the formal examination. A summary of the key points is given at the end of the chapter.

2.2.2 Attitudes

Attitudes are important because they'…allow us to make sense of ourselves; make sense of the world around us; make sense of relationships' Reid (2006:33). Moreover, 'Attitudes affect how people process information about the world and can guide an individual's subsequent actions and behaviour'

(Kayleigh, 2013:3). For example, attitudes are largely responsible for determining why some people enjoy dancing and cooking while others prefer listening to political debates and reading novels. In the context of education, the reason why some students find 'history' more interesting than 'design technology' can be largely attributed to the influence of attitudes. Thus, attitudes strongly shape our overall disposition toward something or someone; this disposition can be either favourable or unfavourable (Owen et al., 2008; El-Faragy, 2007; Williams et al., 2003).

Attitudes, positive or negative are constructed from three primary individual level factors or elements; these are cognitive, affective and behavioural (Feisner, 2014; Barmby et al., 2008; Javaras, 2004). The first of these relates to the beliefs, values and attributes we attach to social or physical phenomena (Feisner, 2014; Cooper, 2012; Bouzidi, 1989). Examples that fall into this category include the belief that 'hard work leads to financial prosperity' or knowing that 'smoking is harmful to health in the long term'. The second component represents our emotional responses or feelings towards different phenomena (Cooper, 2012; Barmby et al., 2008; Akey, 2006). Examples include respect for the law; fear of spiders; love for our parents; feeling annoyed when the train is delayed or elated when our favourite football team wins a match. The third component represents the actions or behaviours that mirror these cognitive and affective dimensions (Hoekesma et al 2009). Examples include continuing to work beyond our contracted hours or staying away from permitted smoking zones. Collectively, these three components form our overall attitude toward something or someone (El-Faragy, 2007; Akey, 2006). A more detailed discussion regarding the nature of attitudes and their effects on learning physics is provided in Chapter 8.

2.2.3 Can Attitudes Change?

This section considers whether attitudes have the capacity to change. This is important because it has a direct bearing on the usefulness of my research when it comes to improving AA in physics. Apart from a few dissenting voices (Chu, 2008; Roediger et al, 2007; Hogg and Vaughn, 2005), the consensus view amongst social and educational psychologists is that attitudes have the capacity to change provided there is a good enough reason to change them (Krosnick and Petty 2014; Metin and Camgoz, 2011; Erdermir, 2009). This prevailing view in the literature is neatly summarized by Adesina and Akinbobola as follows: -

> '…attitude changes...people constantly form new attitudes and modify old ones when they are exposed to new information and new experiences' (Adesina and Akinbobola, 2005:128).

Expanding further, Adesina and Akinbobola, (2005) argue that attitudes can change provided the individual finds the new information or experience compelling enough. For example, a person might decide to discontinue support for a political party over concerns about its new policies on immigration or public transport. Metin and Camgoz, (2011) contend that since attitudes are strongly influenced by cognitive, affective and behavioural factors, a major change in either the cognitive or affective factor may be enough to bring about an overall change in attitude. Krosnick and Petty, (2014) argue that although an attitude can change rapidly, it is more likely that the change will happen gradually; especially with respect to deeply ingrained attitudes that an individual has held over a long period of time. For example, an individual may slowly replace the attitude that the natural environment should be controlled and exploited with the attitude that the natural environment should be respected and protected.

The widespread view amongst social and educational psychologists that attitudes have the capacity to change has important implications for my research. It suggests that we might be able to shift negative AP in a more positive direction, perhaps through some form of intervention. In addition, when we consider the theoretical argument (rooted in AT) that AP should be positively correlated with AA in physics, it opens the possibility of improving AA in physics by inculcating more positive AP; this aspect of my research is addressed in greater depth in Chapter 8. The next section reviews what is already known about the relationship between AP and AA in physics.

2.2.4 Link between Attitudes and Academic Attainment in Science

Studies investigating the relationship between AP and AA in physics are relatively sparse compared to those investigating the relationship between Attitudes towards Science (AS) and AA in science. Moreover, the fact that '…many…researches on attitude towards science have dealt with science in general…,' (Nasr, 2011:101) has attracted a great deal of controversy. Critics contend that students may harbour different attitudes towards chemistry, physics and biology, the three subjects that normally comprise secondary school science (Topping et al., 2011; Eaton and Visser, 2008). By merging them into a single subject namely science, they argue that these differences are not adequately spotlighted. Osborne et al (2009) crystallize these concerns as follows: -

> '…one of the weaknesses in the extant data is the tendency to measure attitudes towards science as a homogeneous construct rather than measuring attitudes to the separate sciences' (Osborne et al., 2009:5).

Nevertheless, despite this criticism it is important to understand what these studies have to say about the relationship between AS and AA in science as this will help contextualize the findings from the relatively few studies that have focused on physics in this respect.

2.2.4.1 Attitudes towards Science and Attainment in Science

Many studies have reported a robust relationship between AS and AA in secondary school science (Ali and Awan 2013; Quereshi, et al; 2012; Çakıcı et al, 2011; Osborne and Dillon, 2008). For example, Narmadha and Chamundeswari (2013) investigated the relationship between AS and AA in science of 422 students (aged 15 to 16) attending several schools in Chennai, India. AS were appraised using the Attitude towards Learning of Science Scale or ALSS (Grewal, 1972) and the marks scored in science were taken from the students' half yearly school examinations. They concluded that: -

> 'The results of the study indicated that attitude towards Science had a significantly positive relationship with the achievement of Science students at secondary level' (Narmadha and Chamundeswari, 2013:117-118).

In another study, Ali and Awan (2013) examined the relationship, (amongst other aspects), between AS and AA in science of 1,885 students (aged 15 to 16) attending several high schools in Pakistan. To measure AS, they used the Test of Science Related Attitudes or TORSA designed by Fraser (1978). The participants' AA was based on formal examination results obtained from the Pakistan Based Examinations Board relating to the Secondary School Certificate (SSC) which broadly equates to the GCSE here in England. They identified a moderate to strong positive correlation between AS and AA in science. They summarize this aspect of their research as follows: -

> 'The findings and results of this study replicated the results of...previous research studies that attitude towards science was positively correlated with the achievement in science' (Ali and Awan, 2013: 715).

Strength of both studies is that they use relatively large samples, especially the Ali and Awan (2013) study. This reduces SE and increases confidence in the reliability of their findings (Field, 2014; Nolan and Heinzen, 2011). In addition, the reliability and validity of the ALSS and TORSA for assessing attitudes is widely accepted by academics across a broad range of disciplines (Shah and Mahmood, 2011). Moreover, both studies use randomized sampling; this reduces the risk of sample bias and increases confidence in the generalizability of their findings (Field, 2014; Nolan and Heinzen, 2011).

Potential weakness of both studies is that they are largely descriptive and show little interest in explaining their findings from a coherent theoretical perspective; also, they tend to shy away from discussing the implications of their findings on potentially improving AA in science. Nevertheless, their principal finding (suggesting a positive relationship between AA in science and WMC) receives strong support from other studies in the wider literature (Ali et al., 2015; Quereshi et al., 2012; Owen et al., 2008; Williams et al., 2003).

The two studies above reflect three broad trends in the wider literature. Firstly, the positive relationship between AS and AA in science appears to be well established. Secondly, many studies point to a positive relationship between the aforesaid variables. However, making direct comparisons between studies is difficult given how researchers have used a variety of approaches to gauge both AS and AA in science. Thirdly, the literature is largely silent when it comes to explaining the relationship between AS and AA in science from a coherent theoretical standpoint. My study bridged this gap in knowledge and understanding. Focusing on physics, I used AT to advance a post hoc explanation to potentially account for the correlation between AP and AA in physics.

2.2.5 Attitudes towards Physics and Academic Attainment in Physics

When it comes to secondary school physics, educational psychologists appear to focus chiefly on understanding the attitudes of learners, especially females, towards post-16 physics and careers in physics and related fields (Acar et al., 2015; Awodun et al., 2014; Fatoba and Aladejana, 2014). Arguably, investigating the relationship between AP and AA in physics has largely gone under the research radar.

The very few studies that have focused in this area report that students with more positive AP tend to obtain better overall test scores or grades in physics compared to those with less positive AP (Veloo et al., 2015; Vahedi and Yari, 2015; Selcuk, 2010; Lawrenz et al., 2009). Key studies which reflect the wider literature in this area (such as it is) are discussed next.

In a major research programme carried out in England, Archer et al., (2020) investigated the attitudes of young people (aged 10 to 19) toward studying post-16 science and their aspirations relating to science careers. A key aim of their research was to understand the factors that shape young people's intentions to continue with post-16 science and pursue a science related career. In addition, they were interested in understanding '...the factors that influence how young people identify as being 'good at science' and/or being 'science-y' (science identities)?' (Archer et al., 2020:4)

Although their primary focus was on science, it also encompassed STEM subjects more broadly. In the 15 to 16 age group (corresponding to the age group of the respondents in my study), Archer et al., (2020) reported that many of the students found science both interesting and engaging. For example, about 60% of the students felt that 'they learn interesting things in science' (Archer et al., 2020:6) and almost 70% believed that 'scientists do valuable work' (Archer et al., 2020:6). However, only about 15% of the students 'aspired to become a scientist' (Archer et al., 2020:6).

To explain these findings, the authors largely draw on the work of the sociologist Pierre Bourdieu. Notably, they introduce the concept of 'science capital' as a specific realisation of Bourdieu's cultural and social capitals (Archer et al., 2020). They define the latter as follows: -

> '...we developed the concept of science capital...as a way of encapsulating all the science-related knowledge, attitudes, experiences and social contacts that an individual may have' (Archer et al., 2020:6).

The concept of science capital can perhaps be understood more clearly via following questions: -

- What do you know? What is the depth of your science knowledge?
- Who do you know? An engineer or scientist for example?
- What is your overall disposition towards science - favourable or unfavourable?
- What are your out of school learning behaviours? For example, do you study science when not in school?

Archer et al., (2020) found that about 5% of the students had high science capital, about 68% had medium science capital and approximately 27% had low science capital. They explain the terms low and high science capital as follows: -

> 'We use the terms 'low' [science capital] and 'high' [science capital] ...as provisional, accessible terms for the academic concepts of exchange-value and use-value capital…' (Archer et al., 2020:7)

Moreover, they found that students with high (or medium to high) science capital were more likely to study post-16 science and have career aspirations linked to science. In addition, these students tended to be white or south Asian boys from professional middle-class families. Based on their findings, Archer et al (2020) conclude that post-compulsory science education is largely the preserve of privileged social groups. To make post-16 science education more socially equitable and inclusive, they contend that science educators should focus on improving the science capital of young people across all social groups, gender, and ethnicities (Archer et al., 2020).

Comparing their main research interests with mine shows that both studies are generally oriented in different directions. For example, my research uses theories largely from the field of educational psychology (IPT and AT) to potentially explain the influence of two cognitive variables (WMC and VSA) and one affective variable (AP) on AA in physics across all social groups. In contrast, Archer et al., (2020) argue that enhancing science capital can potentially make science more equitable and improve aspirations in science related careers for all learners. In addition, their research is largely relational in that they privilege social advantage/disadvantage as an explanatory factor, whereas I am more concerned with individual-level characteristics. However, when it comes to attitudes, there is perhaps less difference. For example, one of the factors that I identified as exerting a strong influence on AP could potentially be understood in terms of science capital and social privilege (Archer et al., 2020). This factor relates to an individual's level of awareness of careers in physics (see Chapter 7, part II). Also, both studies champion an intervention of some kind; I suggest targeting WMC, VSA and AP to potentially improve AA in physics. Archer et al., (2020) advocate developing science capital to make science more appealing and inclusive.

In another major study, Veloo et al., (2015) investigated, amongst other aspects, the effects of AP on AA in physics. They sampled 203 students aged

15 to 16, attending two unrelated schools in the province of Kelatan in Malaysia. To assess AP, they adapted an approach used by Prokop et al., (2007). This approach falls under six broad areas: Interest towards Physics (primary component); Careers related to Physics; Importance of Physics; Physics Teachers; Difficulty in Physics and Physics Equipment. Veloo et al., (2015) AA in physics was based on the students (aged 16) final year examination grades. Taking 'interest in Physics as a key indicator of AP they summarize their outcomes as follows: -

> 'This finding shows that students who have high interest in Physics obtain good grades in Physics and those who have low interest in Physics obtain low grades in Physics' (Veloo et al., 2015: 39-40).

A major weakness of their study is that the instrument they used to assess AP appears not to have been extensively field tested or widely used by other educational psychologists and this makes the reliability and validity of the findings from this instrument more suspect; it also casts further doubt over their generalizability. However, their central finding that AP strongly influence AA in physics broadly resonates with those reported in other studies (Ali and Awan, 2013, Narmadha and Chamundeswari, 2013; Magno, 2003; Williams et al., 2003).

In another study, Vahedi and Yari (2014) investigated, amongst other aspects, AP and AA in physics of 400 students from different high schools in Iran. They used multi-stage sampling, an approach akin to cluster sampling. Although the latter can save time and money, it is generally regarded as less effective in minimizing systematic error and sampling bias; both can potentially undermine the reliability and trustworthiness of the findings (Field, 2014; Nolan and Heinzen, 2011). However, cluster sampling is well suited to investigating attitudes of a particular group or cluster of individuals who fit a particular profile, such as students studying physics at a particular stage in the education cycle. To survey AP, they used a questionnaire which they had designed themselves specifically for this purpose. They claim that their questionnaire has a Cronbach alpha value of 0.91; this indicates a very high level of internal consistency between the items on the questionnaire and enhances its reliability (Field, 2014; Heinzen, 2011). After analysing the data from their investigation, Vahedi and Yari (2014) concluded that, 'The results showed a significant and positive relationship between...attitudes towards physics...with physics achievement' (Vahedi and Yari, 2014:572).

A weakness of their study is that they do not explicitly state how they obtained the data pertaining to the AA of the students in their study; they merely allude to examination grades in physics. There is also no mention of a pilot study having been carried out beforehand and this is potentially problematic given that they used an attitude questionnaire that has not been extensively tested in the field and appears to have been used only in this study. Moreover, although they make some effort to explain the outcomes from the other dimensions of their study, when it comes to this dimension, they largely confine themselves to reporting the positive relationship between AA in physics AP. The literature review suggests their principal finding resonates with those from other studies (Omotade and Adeniyi, 2013; Gill and Bell, 2011; Francisco, 2010; Lawrenz et al., 2009).

2.2.6 Original Contribution

Recapping, a review of the literature suggests that it is skewed in favour of studies investigating the relationship between AS and AA in science (Belgecan, 2012; Cheung, 2009; Adesoji, 2008; Gardner, 2008). Consequently, it is much more limited when it comes to investigating the relationship between AP and AA in physics. In addition, the literature is largely descriptive and falls short of explaining the relationship between the aforesaid variables from any kind of in-depth theoretical perspective. Focusing on physics, I bridged this perceived gap in knowledge and understanding. After independently testing the positive correlation between AP and AA in physics (see Chapter 7), I use AT to advance a post hoc explanation to potentially account for the aforesaid correlation (see Chapter 8). I also identified some of the key affective factors contributing toward the development of AP and explained them from the perspective of AT (see Chapter 8). In addition, by investigating the relationship between AP and AA in physics, my research partly redressed the perceived imbalance in the literature dominated by studies investigating the relationship between AS and AA in science.

2.2.7 Conclusion

This section provided a brief overview of the research aims related to investigating the relationship between AP and AA in physics. It then explained the core attributes of attitudes as broadly understood by many educational psychologists. It then reviewed the evidence suggesting that attitudes have the capacity to change provided there is a compelling reason to change them. The section then explained what is already known about the relationship between AP and AA in physics in the context of the wider literature in this field. Moreover, it identified the perceived gaps in knowledge and understanding and then explained how they were addressed by this study.

Chapter 3 Research Methodology and Methods

3.1.1 Introduction to Part I: Research Paradigm

This chapter is divided into three parts. Part I discusses the research paradigm that underpins the research methodology and methods used in my study. Part II explains how the research paradigm guided the overall research design. Part III focuses on the data collection instruments. Collectively, the three parts represent the overall research methodology and methods used to achieve the aims of my study.

The chapter begins by arguing the importance of grounding research in a specific paradigm. It then discusses the core ontological and epistemological tenets of the post-positivist paradigm that informed and guided my study; the reasons for choosing this paradigm are also explained. The chapter also reflects on the problematic nature of making valid knowledge claims based on theory-laden observations. In addition, the impact of the researcher and the wider research community on the research process and especially on the research outcomes are discussed from this philosophical perspective.

3.1.2 Post-positivist Paradigm

Before undertaking any kind of research, it is important to establish the meta-theoretical perspective (or paradigm) that will inform and guide the research (Macionis, 2012; Gephart, 2008; O'Leary, 2007). Embedding the research in a relevant paradigm is important because it places the study in the wider research arena and allows others to evaluate the findings of the research more readily (Thibodeaux, 2016; Cummings, 2012; Curry et al., 2013). Thus, '…no inquirer…ought to go about the business of inquiry without being clear about just what paradigm informs and guides his or her approach' (Guba and Lincoln, 1994:116).

My research is grounded in the post positivist-paradigm for reasons that will be explained later in the Chapter. Advocates of the post-positivist paradigm contend that all phenomena, physical and non-physical, are real and exist as independent entities waiting to be discovered (Friedrich, 2015; Taylor, 2014; Curry et al., 2013). Thus, 'post positivists... hold to...the principle that external reality awaits our discovery...' (Bernard, 2006:3). Given this philosophical stance, research grounded in the post-positivist paradigm can range from investigating the rotational speed of a carbon atom at very low temperatures to exploring people's attitude towards diet and exercise.

Post-positivists further contend that our observations will be theory laden. For example, in the case of measuring the rotational speed of the carbon atom, theories pertaining to Quantum Mechanics and Newtonian Physics come into play. The ideas and concepts contained in these theories will determine not only how the measurements are taken but also the way in which they are subsequently interpreted and understood.

Thus, from the post-positivist standpoint, preconceived notions and presuppositions contained in these theories will strongly influence the observations and introduce an element of uncertainty. This means that we cannot be sure whether we are observing the 'real thing' or some distorted version of it (Stadler, 2015; Cohen et al., 2011). Consequently, although post-positivists do not deny the existence of either the spinning carbon atom or people's attitude towards diet and exercise, they do question our ability to capture them accurately.

This philosophical stance has important implications for my research. Firstly, it means that the cognitive-affective variables WMC, VSA and AP exist in the sense that they can be measured, albeit indirectly. Secondly, how I measure and understand these variables will be strongly influenced by the theoretical perspectives that I bring to bear on them namely IPT, CLT and AT. Thus, from the post-positivist standpoint, my observations will be theory laden, and this will prevent me from capturing their true nature; the best I can hope for is a close approximation.

3.1.3 Conjectures and Warrants

Post-positivists further contend that another reason why it is impossible to fully understand any given phenomenon is because we can never know everything about it - our information will always be incomplete (Taylor, 2014; Stadler, 2015, Ryan, 2006). Imagine trying to visualize the image contained in a jigsaw puzzle which has several pieces missing; we can never be certain what the final image looks like. For this reason, our theories, ideas and conclusions about a particular phenomenon are essentially conjectural. These conjectures provide us with a warrant, or the right to hold a particular position or belief about the phenomenon. We can maintain this position until a more compelling theory or new information comes to light and invalidates the warrant (Taylor, 2014, Gephart, 2008; Bernard, 2006). Thus, post-positivists argue that human knowledge and understanding is continuously changing (Stadler, 2015; Allan and Seaman, 2011). This has important implications for my study; not least in pointing out that the theories I used to inform my observations and guide my interpretations may be substantially revised in the future.

Even though gaining a complete understanding of a particular phenomenon is not possible, this does not mean that we should stop trying. The central goal of post- positivism is to gradually build up confidence in our understanding of a particular phenomenon. Thus, as our knowledge develops and grows, the phenomenon will come into sharper focus (Stadler, 2015; Macionis, 2012; Guba and Lincoln, 1994). The next section considers the role of the researcher in the research process.

3.1.4 Subjectivity in Research

Post-positivists largely reject the notion of the impartial researcher; someone who is detached from the subject of the inquiry. Instead, they contend that the researcher is closely connected to the subject of the research (Macionis, 2012; Gephart, 2008; Ryan and Walsh, 2006). They argue that even though we may endeavour to remain objective and neutral, our subjective nature will almost certainly influence the research (Richie and Rigano, 2001). This dimension of post-positivism is expressed by Ryan and Walsh (2006) as follows: -

> '...within post-positivism the notion of an objective or detached researcher is seen as a myth...as a researcher you bring your life experiences, values and ways of viewing the world to bear on how you approach any topic...your biographical affinities and experiences are always at play, and they influence... the analysis of the data and the significance of the findings...' (Ryan and Walsh, 2006:37).

However, instead of regarding this as a potential weakness, post-positivists regard it as a strength. How else they argue, can we better understand social and physical phenomena unless we first accept that we have viewed them using our subjective lens? For example, when developing the Theory of Relativity, Einstein imagined what it would be like to ride a light beam as it travelled through the solar system (Isaacson, 2007).

This does not mean that my personal views and opinions give me the right to carry out my research exactly as I please or to make unsubstantiated knowledge claims. From the post-positivist standpoint, any knowledge claims I make must emerge from the methods and practices that are broadly recognised and accepted by my research community, namely educational psychology.

Thus, from the post-positivist perspective, the importance of the wider research community to the individual researcher cannot be over stressed. In my case, in addition to providing me with a template for carrying out my research, the latter provides an infrastructure through which I can advance my research goals and reach out to other researchers in my field (Nolan and Heinzen, 2011; Raelin, 2008). Crucially, it also means that my knowledge claims will have been informed and guided by my disciplinary community; this will give them an inter-subjective rather than merely a subjective dimension and arguably reinforce their credibility (Gephart, 2008; Ryan and Walsh, 2006).

From the post-positivist perspective, the individuals who take an interest in my research will also view the latter through their own subjective lens as pointed out by Charmaz (1999) 'Readers come to our stories with their own knowledge, experience and meanings…they have views...', (Charmaz, 1999:374). Of course, we must not forget that those who took part in my study will also view their involvement in the research subjectively and this will undoubtedly affect their reactions, responses and behaviours from a post-positivist standpoint. This means that all knowledge claims can be contested because they are based on, '…multiple interpretations of the phenomenon...' (Cohen et al., 2011:27). Importantly, instead of regarding this as a potential problem, post-positivists welcome it. They contend that only through continuous critical reflection can we ever hope to develop and improve our understanding of social and physical phenomena (Thibodeaux, 2016; Robson, 2011).

I find this aspect of post-positivism especially appealing. However, this is not the only reason why I chose to embed my research in this paradigm. Another key reason is that the latter takes a much more inclusive view about what counts as knowledge. It places qualitative data on a par with quantitative data (Thibodeaux, 2016; Guest et al., 2012; Ryan and Walsh, 2006). Thus, 'soft data' such as that gleaned from focus group interviews is considered equally important and trustworthy as 'hard data' obtained from a scientific experiment or empirical test. Thus, post-positivists do not regard research as exclusively quantitative or qualitative. Instead, they argue that '…qualitative and quantitative research, in combination, provides a better understanding of a problem or issue than either approach alone' (Bulsara, 2014:6). When operating in tandem the two approaches reinforce and complement each other and this can potentially lead to a deeper and more intimate understanding of the phenomenon under investigation (Thibodeaux, 2016; Adams and Cox, 2008; Hanson, 2008).

Moreover, the 'mixed methods' approach appears to be growing in popularity across a wide range of academic disciplines as noted by Guest et al., (2012), 'Mixed methods research, that is, research that integrates qualitative and quantitative data, is increasingly common' (Guest, et al., 2012: xv). In summary, the ontological and epistemological dimensions of post-positivism strongly influenced the methodology and methods I employed in my research. It also strongly influenced the way in which I analysed and interpreted the data and the way in which I presented the findings. The next section explains the importance of reflecting on the potential impact of our positionality on the research.

3.1.4.1 Positionality and Reflexivity in Research

From the post-positivist standpoint, reflecting on positionality can help us to better understand how our biography could potentially impact the research. Holmes (2020) explains this as follows: -

> '...positionality should show where and how the researcher believes that they have, or may have, influenced their research…' (Holmes, 2020:3).

Positionality considers the possibility of a researcher's lived experience influencing the research process, that is, people in different 'positions' (understood in terms of a multidimensional space of class, gender, ethnicity, religion, sexuality and various aspects of biography) may engage in the research process in different ways. For example, they may ask different research questions, prefer different methodologies, interpret data in different ways, and draw different conclusions from the analysis. Moreover, we should communicate the potential impact of our personal position or standpoint on the research to the reader (Holmes, 2020; Delamont, 2018). This will enable the reader to make a more informed decision about the reliability and validity of the research findings. However, Delamont (2018) argues that we will probably never completely understand the full impact of positionality on the research. In part, this is because we may not be fully conscious of the different dimensions that shape our personal standpoint in relation to the research. Nevertheless, Holmes (2020) argues that we should still strive to understand the potential impact of positionality on the research process.

Closely allied with the notion of positionality is the concept of reflexivity. For Holmes, (2020): -

> 'Reflexivity informs positionality. It requires an explicit self-consciousness and self-assessment by the researcher about their views and positions and how these might, may, or have, directly or indirectly influenced the design, execution, and interpretation of the research data findings' (Holmes, 2020:2).

Reflexivity generally involves examining our judgements, beliefs, and practices during the research process and how these may have shaped the research. If positionality largely relates to what we know and believe, then reflexivity broadly relates to what we do with this knowledge and these beliefs in the context of the research. It requires an open and frank discussion with oneself, and the recognition that the researcher is part of the research (Holmes, 2020; Delamont, 2018).

Savin-Baden and Major (2013) suggest that we can better understand the effects of positionality and reflexivity on the research process by focusing on the following dimensions: -

- Personal values, beliefs, and experiences
- Bias and prejudice
- Ontological and epistemological position
- Race and ethnicity
- Age
- Gender
- Power relations between the researcher and the respondents

Adapted from Savin-Baden and Major (2013)

The potential influence of each dimension on my research is discussed next. My personal values, beliefs and AS were strongly shaped by my parents and by my own experiences of science education. My parents came from Pakistan in search of a better life in the UK in the late 1950's; I was born shortly after they arrived. My father found employment as a mill worker and eventually went on to become a foreman. After the mills closed permanently, he opened a grocery store; my mother was a full-time housewife. Although my parents had little formal education, they wanted me to do well at school. They would constantly tell me how privileged I was to be receiving an education, and a 'free one' at that. They wanted me to do well in the sciences and to pursue a career in medicine or engineering. Consequently, I came to value science education highly and tried hard to succeed in science. I found that I had a natural aptitude and interest in physics, and I went on to complete a degree in this subject. I decided to pursue a career in science education and became a secondary school physics teacher.

Thus, my values and beliefs regarding science education were initially shaped by my parents and then reinforced by my own largely positive experiences as a student and as a teacher. I strongly believe that education in general (and science education in particular) should be respected and valued, and that we should endeavour to make the most of it. However, I accept that not everyone necessarily shares these views. This represents an important dimension of positionality, namely that: -

> ‘...researchers should not...make any assumptions about other’s perspectives and world-view and pigeonhole someone based on their own (mis)perceptions of them.’ (Holmes, 2020:2).

We should be especially wary when making assumptions about other people’s views or their level of knowledge pertaining to a given phenomenon (Holmes, 2020). For example, I assumed that many of the participants in my research would have a reasonable appreciation of the practical applications of physics in the real world. This assumption was based on my personal experiences, both as a student and as a teacher. However, my research findings revealed that this was not the case (see Chapter 7, part II). For example, few participants recognised the contribution that physics is making in developing technologies that sustain modern societies (see Chapter 1, section 1.3). This example highlights the need to be extremely cautious when making assumptions. If we do make assumptions in our research, the reasons for making them should be clearly explained (Holmes, 2020; Delamont, 2018).

Also, even though I tried to remain impartial and objective, my personal bias and prejudice may have influenced the research process. For example, I may only have focused on questions that I believed to be especially important. Reif (2008) followed a similar course of action as a researcher, ‘I have attempted to be judiciously selective by focusing on issues that I deemed most important...’ (Reif, 2008: xvi). In addition, given that I am favourably disposed towards physics, I may have under-reported or downplayed the importance of unfavourable views about physics espoused by the respondents. To reduce this possibility, I systematically (and objectively) reviewed unused data to identify any relevant information that I may have overlooked.

I articulated my ontological and epistemological position and its effects on my research in some depth in Chapter 3, part I. Summarising, I reside in the post-positivist paradigm; however, this was not always the case. At the beginning of my research, I was firmly rooted in the positivist paradigm. However, over the course of the research I came to believe that the post-positivist paradigm was a better fit for me both on a personal level and in relation to my research. Consequently, post-positivistic thoughts and ideas coloured all aspects of my research, and more especially the methodology and methods I used to carry out my research.

My race and ethnicity may also have impacted the research process, especially when collecting qualitative data linked to AP. There is evidence in the literature suggesting that: -

> '...the closer one's race and ethnicity is to the person being observed or interviewed the more likely the truthfulness of the responses…' (Januszka et al., 2007:40).

In my research, it is possible that the participants who felt connected with my race or ethnicity responded more openly and freely compared to those who did not. Moreover, my behaviours may have been influenced by whether I perceived the respondents to belong to the same racial or ethnic group as myself. I took several steps to reduce this possibility. For example, I tried to avoid shaking or nodding my head, raising my eyebrows, agreeing or disagreeing with the participants' responses. I also tried to avoid praising or favouring some participants above others.

My age may also have made an impression on the research, especially when exploring the respondents' AP (see Chapter 3, section 3.2.7.2). Summarising, there is evidence in the literature suggesting that the closer the researcher is in age to the participants, the greater the likelihood that the participants will give more frank and open responses (Holmes, 2020; Delamont, 2018; Januszka et al., 2007). Consequently, the fact that I was much older than the participants may have coloured their responses, especially when completing the attitude questionnaire and in focus group interviews. The steps I took to reduce this possibility are discussed in Chapter 3, section 3.2.7.2. Also, my gender may have influenced the research process; for example, Archer et al., (2020) report that physics is perceived as a masculine subject by many school-age students. As a male researcher, I may have reinforced stereotypes and produced stereotypical responses, especially in the focus group interviews on the participants' AP. To minimise this possibility, I encouraged the respondents to express their views freely and openly.

In Chapter 3, section 3.2.7.1 I discussed the power relations between myself and the respondents. Summarising, I argue that I held the dominant position. The resulting power imbalance may have influenced some of the respondents' responses, perhaps more especially when completing the attitude questionnaire and in focus group interviews. The steps that I took to reduce this possibility are discussed in Chapter 3, section 3.2.7.1. The next section shows how post-positivism framed the way in which I conceptualized my research.

3.1.5 Conceptual Framework

Figure 1 below provides an outline of how the post-positivist paradigm influenced the way I conceptualized my research.

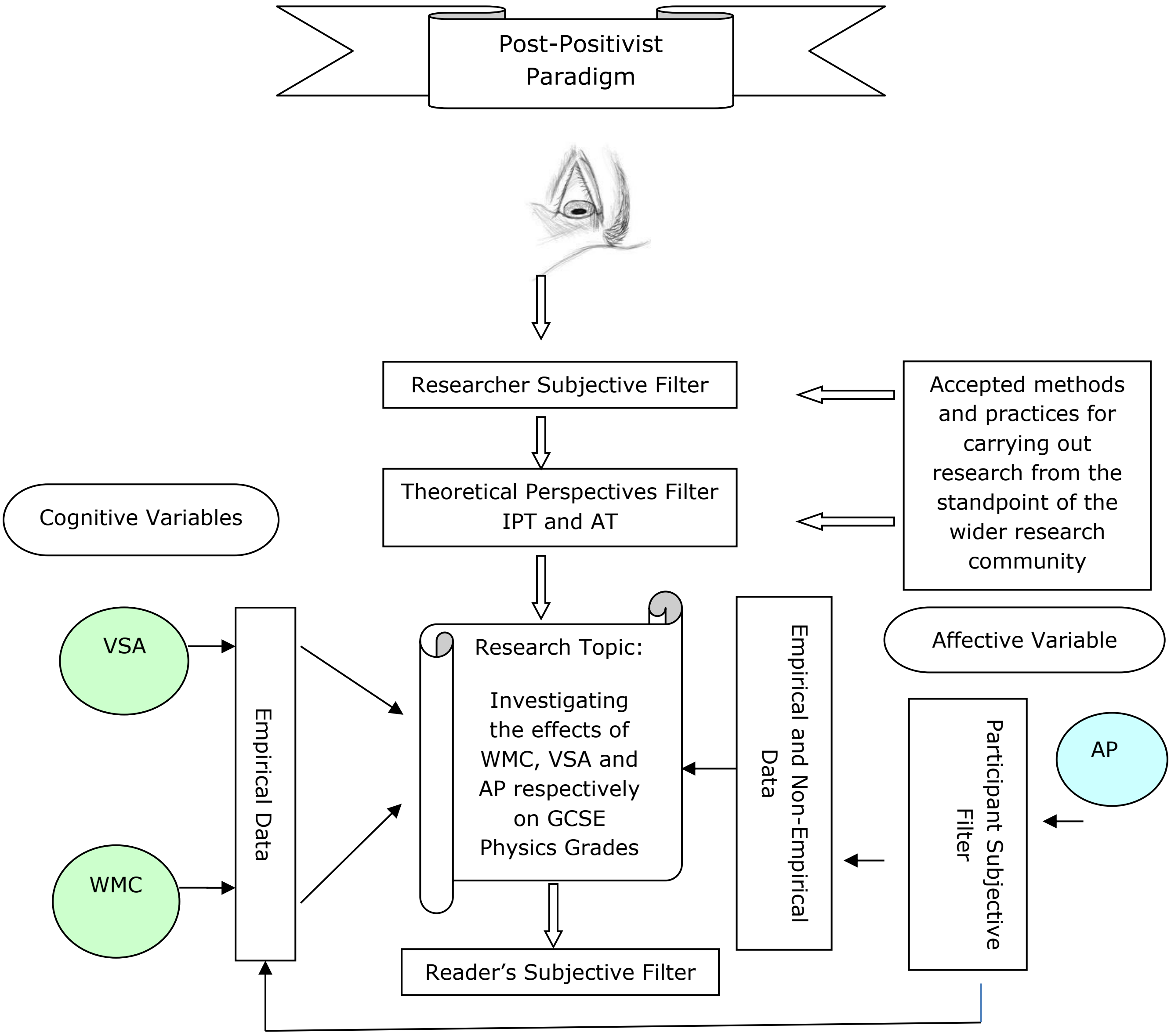


Figure 1: Conceptual Framework

Key for Figure 1

- VSA (Visual Spatial Ability - Cognitive Variable)
- WMC (Working Memory Capacity - Cognitive Variable)
- AP (Attitudes towards Physics - Affective Variable)
- IPT (Information Processing Theory)
- AT (Attitude Theory)

Beginning from the top and moving down, the first thing to note from Figure 1 is how my subjective nature (guided by the wider research community), will influence my observations and interpretations. Secondly, as denoted by the Theoretical Perspectives Filter, leading theories in the field of educational psychology (namely IPT and AT) will also strongly influence my observations and explanations. Thirdly, interested individuals (including physics teachers, curriculum planners and educational psychologists), will view my research using their own subjective '...frames of reference or meaning repertoires' (Ryan and Walsh, 2006:37). Fourthly, the schematic outlines how the cognitive variables will be measured using empirical tests designed specifically for this purpose. In addition, it shows how the affective variable will be measured both quantitatively and qualitatively. Finally, the schematic highlights how the subjective nature of the participants will influence their responses in the various 'tests'.

3.1.6 Operationalizing the Research

Figure 2 below shows how post-positivist ideas shaped the way I operationalized my research.

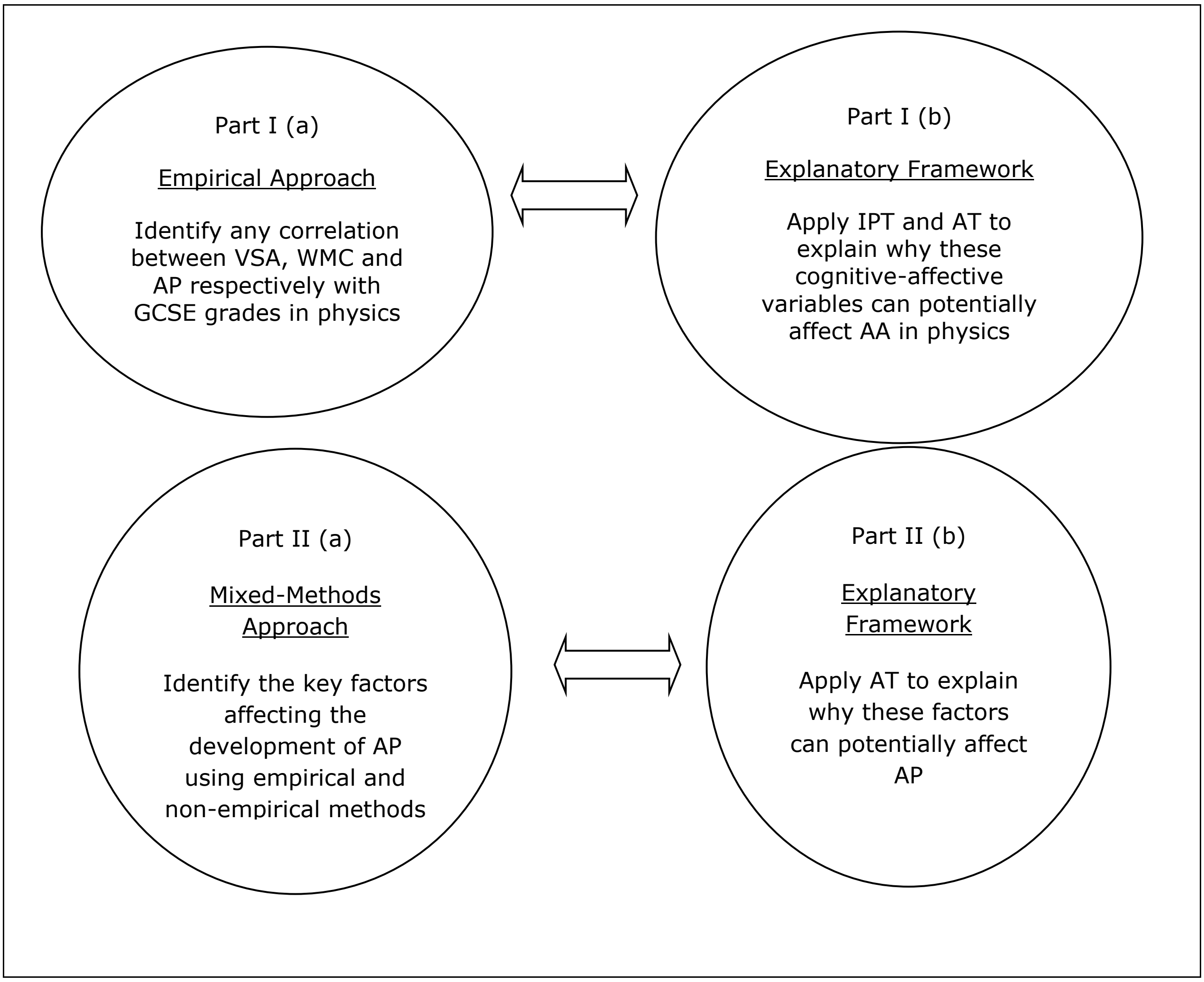


Figure 2: Research Procedure

In part I (a) of Figure 2, I investigated whether there was any correlation between the cognitive-affective variables respectively with GCSE grades in physics. In part I (b) I used the theoretical lens afforded by leading theories in educational psychology to explain why the aforesaid variables might influence attainment in physics. In part II (a) I used a mixed-methods approach to identify the principal factors influencing the development of AP. In part II (b) I applied AT to account for why these factors impact AP. In addition, using the aforesaid theoretical perspectives I explored whether these cognitive-affective variables could be improved or enhanced through targeted training. When it transpired that there were no theoretical reasons for why they could not, it opened the possibility of raising standards in physics by specifically targeting the aforesaid variables – of course provided there was a significant positive correlation between them.

3.1.7 Conclusion

The ontological and epistemological perspectives that underpin my study are grounded in the post-positivist paradigm. The latter states that physical and non-physical phenomena are real and have an existence that is external to the researcher. Unfortunately, we will never be able to fully grasp their true nature for three important reasons. To begin with, advocates of post-positivism argue that instead of being impartial and detached, researchers are closely tied-up with the subject of their research. This means that they will probably stamp their own subjective nature (and that of the wider research community to which they belong) on the research process including the observations. This will probably distort the latter in some way and possibly prevent us from understanding the true nature of the subject being studied.

Secondly, all observations are theory laden and this ‘muddies the waters’ further and makes it even more difficult to capture the actual mode of existence of the subject under study. Thirdly, post-positivists contend that we will probably never be able to totally comprehend every aspect of the subject because our information about it will almost always be incomplete – it is almost impossible to know everything about something. Post-positivists also advocate combining empirical and non-empirical methods whenever possible. They argue that using a ‘mixed methods’ approach can afford a deeper understanding compared to using either approach alone.

3.2.1 Introduction to Part II: Research Design

This section of Chapter 3 (namely part II) provides a detailed exposition of the research design that I employed to complete my investigation. In particular, the following aspects of the research design are covered in-depth: research integrity and validity; research methods; piloting the methods; hypotheses testing; causality; statistical and thematic analysis; inductive and deductive reasoning; approaches to sampling; potential sources of bias and the role of ethics in the research process. The concluding section provides a summary of the key ideas and discussion points covered in this part of Chapter 3.

3.2.2 Deductive and Inductive Reasoning

The decision to utilise both deductive and inductive reasoning was strongly influenced by my research aims (see Chapter 1, section 1.1). The deductive dimension was used to address the first three aims and the inductive dimension was used to address the fourth aim (see Chapter 1, section 1.1). Thus, although my research is largely deductive, it does include an inductive component. Specifically, my research is deductive in the sense that I used well established theories (IPT and AT) to potentially explain the statistically significant positive correlation between GCSE grades in physics and WMC, VSA and AP respectively (see Chapter 4, section 4.3 and 4.4 and Chapter 7, section 7.1.3). Given that I went from the general to the specific, this part of my research represents the deductive dimension (Russell, 2014; Cumming, 2012; Leon et al., 2011).

My research is inductive in the sense that I used the data on attitudes to identify the factors that possibly influence AP (see Chapter 7, part II). This was done as follows: -

- I used the method advocated by Saris and Gallhofer (2014) to analyse the quantitative data on attitudes (see Chapter 3, section 3.2.5.1).
- I analysed the qualitative data on attitudes using thematic analysis (see Chapter 3, section 3.2.5.2).

I then used the theoretical lens afforded by AT to potentially explain the influence of these factors on AP (see Chapter 8). Given that I went from the specific to the general, this part of my research represents the inductive dimension (Russell, 2014; Cumming, 2012; Leon et al., 2011).

3.2.3 Research Integrity

Central to research integrity is the notion of validity (Macionis, 2012; Basit, 2010). In its broadest sense, 'validity questions...the extent to which a research fact or finding is what it is claimed to be' (Bassey, 1999:75) and if the findings of the research are consistent with the original intentions (Newton and Shaw, 2014; Field, 2013; Porta, 2008). Thus, validity spotlights whether the research has done what it set out to do and if the methodology and methods employed in the research provide an epistemological warrant for the claims being made (Newton and Shaw, 2014; Punch, 2009). Although validity can be assessed in different ways, arguably the most important involves understanding '…how well the study translated or transformed an idea or construct into a functioning and operating reality…' (Drost: 2011:116).

In the case of my study, this proved particularly challenging because the individual level cognitive-affective variables of interest (WMC, VSA and AP) are widely perceived as hypothetical constructs by educational psychologists; therefore, they cannot be observed or measured directly. Chapters 5 and 8 discuss this dimension of my research in much greater depth. To overcome this difficulty (and in keeping with post-positivist ideals), I used proxy or stand-in measures instead. Specifically, quantitative and qualitative data on the participants' AP were collected using a questionnaire and focus group interviews respectively. The WMC and VSA of the participants were measured using two independent tests namely, the Digit Span Backwards Test (DSBT) and the Purdue Spatial Visualization Test of Rotations (PSVT: R) respectively (see section 3.3.1). Similarly, it was not possible to measure the dependent variable Academic Attainment (AA) directly because the latter is also widely perceived as a hypothetical construct by educational psychologists. Consequently, GCSE grades in physics were used to operationalize and represent AA (see section 2.1.8). Figure 3 below shows the overall approach that I used in my research in more detail.

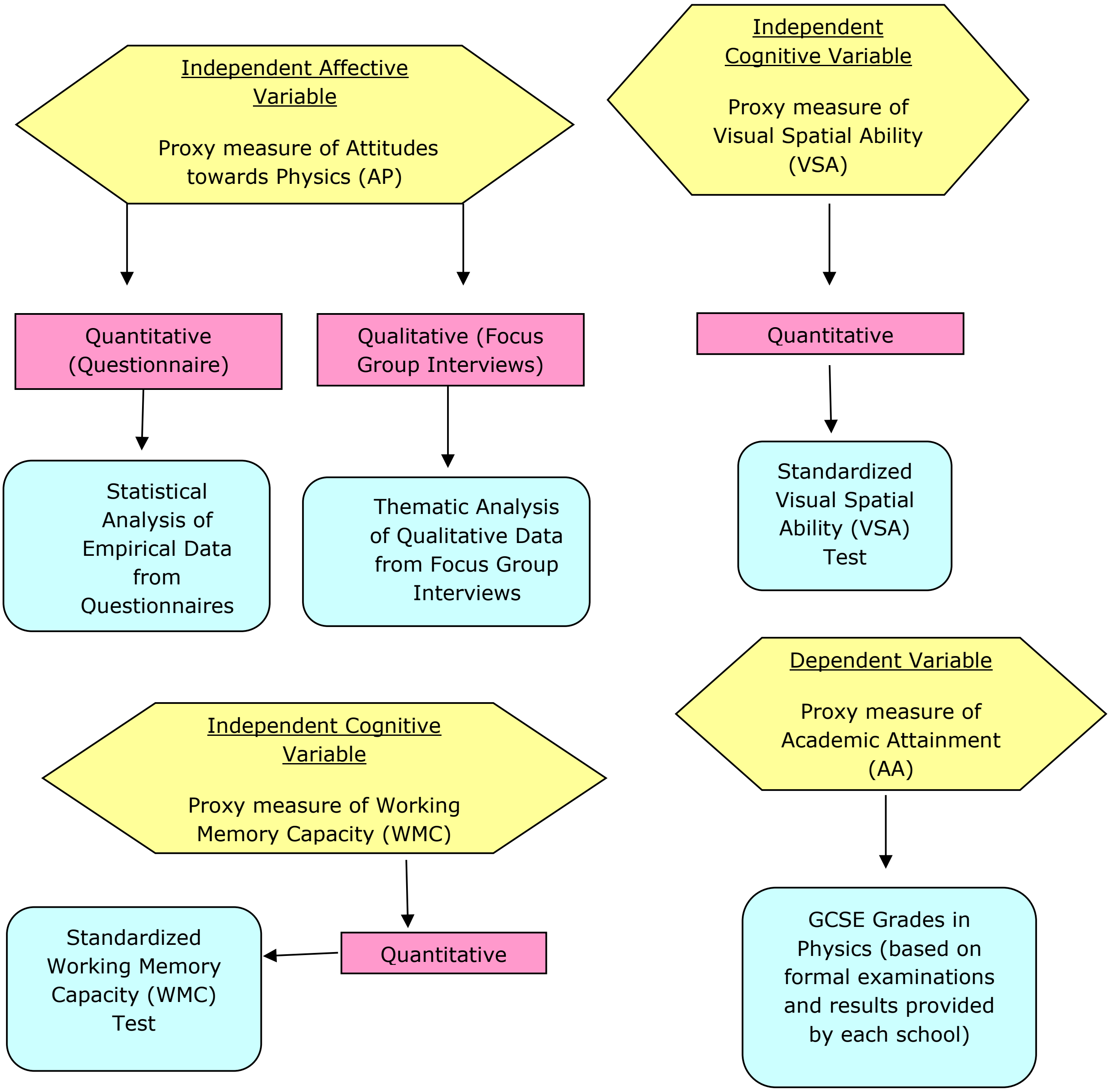


Figure 3: Research Methods

The data obtained from the aforesaid data collection tools were subsequently used to determine the nature and strength of the correlation between GCSE grades in physics and the aforesaid cognitive-affective variables respectively. Chapter 4 discusses the correlational analysis pertaining to the two cognitive variables and Chapter 7 discusses the correlational analysis pertaining to the affective variable. The data were also used to explore the individual level key factors influencing the development of AP. Before carrying out the actual study however, all aspects of the research methodology and methods were tested beforehand via pilot study. As discussed in the next section, the experience gained from the pilot study proved extremely useful in guiding the main investigation.

3.2.3.1 Piloting the Methods

Before beginning the primary study, a pilot study was carried out with 15 students (aged 15 to 16) attending a local state funded secondary school in Bradford. The school was not connected to the two schools who took part in the main study. The guidelines on ethical research stipulated by the British Ethical and Research Association (BERA, 2011) were strictly followed and permission from the head teacher; parents and the participants was secured beforehand. The benefits of carrying out a pilot study are clearly explained by Leon et al (2011) as follows: -

> ‘The...purpose of conducting a pilot study is to examine the feasibility of an approach that is intended to ultimately be used in a larger scale study. This applies to all types of research studies...Pilot results can inform…modifications needed in the design of a larger…study’ (Leon et al., 2011:626-627).

In particular, the pilot study allowed me to trial key aspects of the research process before carrying them out in the main study. These aspects

included: -

- Logistical planning and administration
- Time and resource management
- Testing the 'user-friendliness' of the data collection instruments in terms of administering and completing them
- Analyzing and evaluating the subsequent qualitative and quantitative data
- Gaining familiarity with the principal software package used to analyse empirical data, namely SPSS (Statistical Package for the Social Sciences).

In addition, the pilot study afforded me the opportunity to gain valuable experience in managing or 'chairing' a focus group interview when exploring the participants AP. The lessons learned from the pilot study informed the larger study. The full benefits accrued from the pilot study are discussed in the next chapter. The next section explains how the strategic aims of the study were operationalized.

3.2.4 Testing Hypotheses

The first strategic aim of the study involved investigating if there was any statistical association between the individual level cognitive-affective variables and GCSE grades in physics. In order to do this, it was necessary to translate this research aim into a form that could be tested using appropriate statistical methods (Wilcox, 2017; Russell, 2014; Guest et al, 2012). Guided by the core tenets of the post-positivist paradigm, this was achieved as follows: -

1. The first strategic aim was translated into a series of null hypotheses (and corresponding alternative hypotheses).
2. A prediction was made regarding whether I should expect to find a correlation between the variables under investigation.
3. An appropriate statistical parameter for spotlighting any potential correlation between the variables was selected.
4. A significance level for the purposes of statistical analysis was chosen.
5. The statistical analysis was then carried out on the empirical data obtained from the data collection instruments.
6. The null hypotheses were rejected (or not rejected) based on the outcomes from the statistical analysis.

Each step in the process outlined above is addressed next.

Null Hypotheses

The null hypotheses were formulated as follows: -

i. H_0: There is no linear correlation between Visual spatial Ability (VSA) and GCSE physics grades.
ii. H_0: There is no linear correlation between Working Memory Capacity (WMC) and GCSE physics grades.
iii. H_0: There is no linear correlation between Attitudes towards physics (AP) and GCSE physics grades.

Alternative Hypotheses

The alternative corresponding hypotheses were formulated as follows: -

iv. H_1: There is a linear correlation between Visual spatial Ability (VSA) and GCSE physics grades.

v. H_1: There is a linear correlation between Working Memory Capacity (WMC) and GCSE physics grades.

vi. H_1: There is a linear correlation between Attitudes towards physics (AP) and GCSE physics grades.

3.2.5 Product Moment Correlation Coefficient

The Product Moment Correlation Coefficient (PMCC or r_s) was chosen to test the null hypotheses shown above. The latter measures the strength of linear correlation between two variables (e.g., X and Y) on a scale ranging from -1 to +1. A value of -1 indicates a perfect negative linear correlation; 0 indicates that there is no linear correlation and a value of +1 suggests a perfect positive linear correlation (Field, 2013; Goodman, 2008). In my study, X represents the independent variable (WMC, VSA or AP) and Y represents the dependent variable (GCSE grades in physics). In addition, a r_s value between: -

- 0.2 and 0.39 indicates a weak correlation between X and Y
- 0.4 and 0.59 indicates a moderate correlation between X and Y
- 0.6 and 0.79 indicates strong correlation between X and Y

(Wilcox, 2017; Nachmias and Guerrero, 2014; Russell, 2014).

Normally, we only reject the null hypothesis (H_0) in favour of the alternative hypothesis (H_1) if the r_s value is higher than a predetermined critical value, commonly known as the p-value (Russell, 2014; Qureshi et al., 2012; Nolan and Heinzen, 2011). The p-value indicates whether the evidence against the null hypothesis being true is sufficient to warrant its rejection. Dorey (2010) explains this as follows: 'The only question that the p value addresses is, does the experiment provide enough evidence to reasonably reject H_0' (Dorey, 2010:2297). Many researchers generally set the p-value at the 5% (or 0.05) level of significance. This means that the likelihood of obtaining r_s greater than the critical value even if there is no correlation is 5% at most – in other words very unlikely (Wilcox, 2017; Saunders et al., 2007; Singh, 2007). Figure 4 below shows the correlational pathways that were explored in my study.

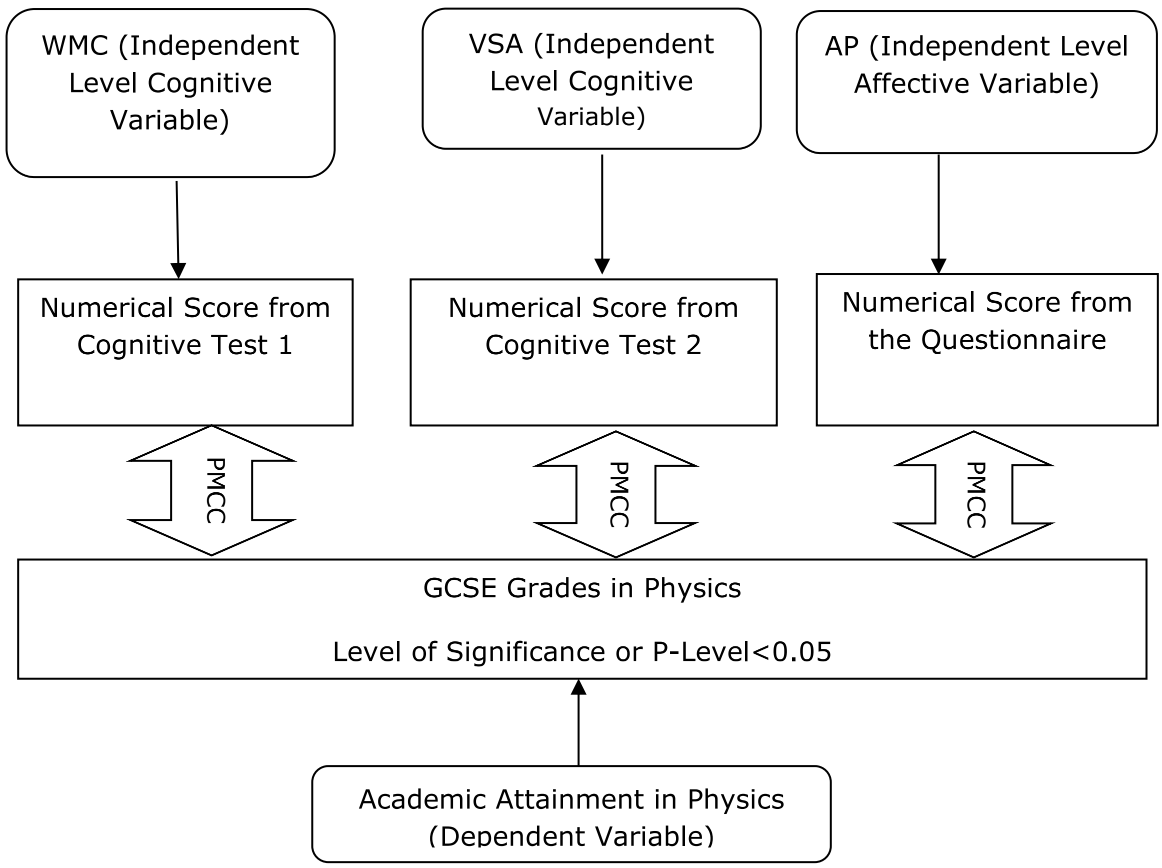


Figure 4: Correlational Pathways

Figure 4 above shows how each individual level cognitive-affective variable was gauged using a suitable proxy measure. It also shows all the potential correlational pathways between the cognitive-affective variables and GCSE grades in physics that were tested using the PMCC (or r_s). A full discussion of the data collection instruments that I used in my study is given in the next section of Chapter 3.

3.2.5.1 Analysis of Key Factors related to AP

To help identify the key factors that may have strongly shaped the respondents' AP, the study drew on the thoughts and ideas of Saris and Gallhofer, (2014). They suggest that we can potentially identify an important factor if the majority of the participants (two thirds or better) respond in broadly similar ways to a cluster of interrelated statements on the questionnaire. For example, the extract below shows the responses of the majority of the participants to the following statements on the questionnaire: -

- Statement: I look forward to my physics classes.

  Majority Response: Disagreed or Strongly Disagreed.

- Statement: I enjoy my physics lessons.

  Majority Response: Disagreed or Strongly Disagreed.

- Statement: When I am doing physics, I am bored.

  Majority Response: Agreed or Strongly Agreed.

- Statement: When I am doing physics, I pay attention.

  Majority Response: Disagreed or Strongly Disagreed.

- Statement: I look forward to spending time in the laboratory doing practical investigations.

  Majority Response: Agreed or Strongly Agreed

Following the thoughts of Saris and Gallhofer, (2014) these responses were interpreted as potentially reflecting the strong influence of the perceptions of physics lessons on the respondents' AP. In another example, the extract below shows the responses of the majority of the participants to the following statements on the questionnaire: -

- Statement: My physics teacher has high expectations of what students can learn.
  Majority Response: Agreed or Strongly Agreed

- Statement: My physics teacher believes that all students can learn physics.
  Majority Response: Agreed or Strongly Agreed

- Statement: My physics teacher wants us to really understand physics.
  Majority Response: Agreed or Strongly Agreed

Using the interpretive lens afforded by Saris and Gallhofer, (2014) these responses were deemed to point to the important influence of the physics teacher on the respondents' AP. Reflecting my personal interest, four of these key factors were then explored more deeply in the focus group interviews as part of the discussion topics (see Appendix 4). It was not possible to investigate all the factors in the focus group interviews because of the 20-minute time limit imposed by the two schools that took part in my study. Part II of Chapter 7 provides a full list of these key factors, and includes an in-depth discussion of their possible influence on the respondents' AP.

3.2.5.2 Thematic Analysis

Thematic Analysis (TA) was used to interrogate the data obtained from the focus group interviews on AP. The review showed that numerous studies across multiple academic disciplines have used this technique to analyse and evaluate qualitative data (Liamputtong, 2013; Shields and Rangarjan, 2013; Saldana, 2009). It also appears that TA is especially preferred by researchers engaged in small-scale studies (typically comprising 5 to 15 participants). Given that I interviewed 10 participants, my study falls firmly in the aforesaid category.

At its core, TA involves identifying recurring themes or shared perceptions in the qualitative data (Wilcox, 2017; McNiff, 2016; Emmel, 2013). As to what counts as a theme, Braun and Clarke (2006) suggest that: -

> 'A theme captures something important about the data in relation to the research question and represents some level of patterned response or meaning within the data set' (Braun and Clarke, 2006:82).

Elaborating further, the authors contend that a theme can represent the shared views and perceptions of a group of people regarding some phenomenon. For example, during the focus group interviews, several participants stated that mathematics made learning physics difficult, and I deemed this response to represent a theme. In another example, most of the participants stated that they enjoyed doing experiments and I recorded this as an important recurring theme. In addition, Braun and Clarke (2012, 2006) suggest that when seeking out themes in qualitative data it is important to generate codes to help categorize repeated words, phrases, ideas and trends in the data. In the context of my study the latter included: 'lessons are hard'; 'lessons are boring'; 'some bits in physics are interesting'; 'lab work is good'; 'teacher goes too fast' etcetera. In effect, when analysing the qualitative data on AP I adopted the approach advocated by Braun and Clarke (2012; 2006). By closely following their advice: -

- I thoroughly familiarized myself with the data.
- I methodically inspected the data for repeating words and phrases and patterns of expression and classified these using self-generated codes.
- I used the coded data to identify emerging themes, shared views and perceptions between the codified (and reassembled) data.
- I used the restructured data to help me to better interpret and make sense of the patterns of meaning.

The skills and experience gained from analysing and interpreting the qualitative data from the pilot study proved enormously beneficial at this time. The next section considers the major drawbacks associated with this approach.

3.2.5.3 Drawbacks Associated with Thematic Analysis

One of the main criticisms of TA relates to the idea of reductionism, a term used to describe the process of breaking up a data set into smaller pieces and then placing these pieces into categories that reflect a particular pattern, theme or viewpoint (Creswell, 2014; Liamputtong, 2013; Bryman, 2008). Some scholars and academics contend that this approach can potentially reduce the cohesiveness of the data set. They argue that by cutting-up the data into smaller fragments, a study may lose sight of the bigger picture, or the broader context afforded by the complete dataset (Liamputtong, 2013; Bryman, 2008). However, given the small-scale nature of the present study, the likelihood of this eventuality happening was deemed to be quite small. If the study had been much larger in both scope and scale, the possibility of missing something important in the wider data (by fragmenting it) would have been higher and therefore of greater concern (Liamputtong, 2013; Guest et al., 2012; Bryman, 2008).

Another potential drawback of Thematic Analysis (TA) relates to concerns over the reliability of the findings. The basis of this contention is rooted in the argument that different researchers may analyse and evaluate the qualitative data in different ways. Reminding us of this possibility, Guest et al (2012) point out how, '...interpretation goes into defining the data items...as well as applying codes...' (Guest, et al., 2012: 11). Consequently, different researchers may reach different conclusions when analysing the same qualitative data (Liamputtong, 2013; Guest et al., 2012; Bryman, 2008). In the context of my study, other researchers may have analysed and interpreted the qualitative data on AP differently to the way I did and consequently their findings may have differed from mine. Therefore, in order to instil greater confidence regarding my interpretation of the qualitative data, I analysed and interpreted the data as openly and as transparently as possible. The findings pertaining to the analysis and interpretation of the qualitative data using thematic analysis can be found in Chapter 9.

3.2.6 Opportunistic Sampling

The two schools that took part in my study had previously employed me as a physics teacher and because of this prior association many academics would probably regard this as an example of opportunistic sampling (Nachmias and Guerrero, 2014; Nolan and Heinzen, 2011). Given that I was a lone researcher with limited resources and a tight time budget, opportunistic sampling provided a simple, effective and direct method of obtaining a sample. Unfortunately, this approach also increased the risk of sample bias (Nachmias and Guerrero, 2014; Cumming, 2012; Adams and Cox, 2008). In relation to my study, this means that these two schools might not fairly represent all secondary schools in Bradford. Consequently, generalizing any of the outcomes from my research to the wider population potentially carries a relatively high risk (Malik and Shujja, 2013; Carman et al., 2012; Tatlah et al., 2012). However, given that this was a small-scale explorative study, it was not my intention to generalize the outcomes to the wider population. Instead, the purpose of my study was to provide a platform for other researchers to expand and develop. Before discussing the methods used to select the two samples, a brief profile of the two schools that took part in my study is given next.

3.2.6.1 Sample Size

I used random probability sampling to compile two samples, one from each school. This approach reduced the risk of sample bias because it ensured that every student in Year 11 had an equal chance of being selected from either school (Nachmias and Guerrero, 2014; Nolan and Heinzen, 2013; Macionis, 2012). All the participants in the sample were following the AQA syllabus and were working toward a GCSE in Additional Science. The senior management team at each school determined the number of participants in each sample. Consequently, two samples comprising 45 and 55 participants were drawn up. Although these samples were quite small, nevertheless, they were sufficient for the purposes of correlational analysis, which requires at least 30 participants (Wilcox, 2017; Hinton et al., 2014; Ryan, 2013).

In addition, I also carried out two focus group interviews, one at each school. Each focus group comprised 5 students. The size was based on the recommendation made by Adams and Cox, (2008) who suggest that ‘A focus group should not exceed six... participants...and it should also be no smaller than three people’ (Adams and Cox: 2008:24). The students who comprised the sample were randomly selected from the two larger samples.

3.2.7 Sources of Potential Bias

Bias is an unwanted guest in research. It can seriously distort the data and discredit the outcomes or findings based on that data (Creswell, 2014: Cohen et al., 2011). The important sources of potential bias and the steps that can be taken to reduce their effects are discussed below.

3.2.7.1 Investigator Effect and Demand Characteristic

The Investigator Effect is based on the idea that the researcher may influence the responses or behaviours of the participants in some way (Russell, 2014; Goodwin and Goodwin, 2013; Shields and Rangarjan, 2013). When carrying out focus group interviews, I may unknowingly have given out subtle physical cues (for example through my body posture and facial expressions) which some interviewees may have perceived as signals to respond in a particular way (Newton and Shaw, 2014; Field, 2013; Goodwin and Goodwin, 2013). In order to reduce these effects (commonly referred to as Demand Characteristics), I maintained a relaxed but neutral demeanour when 'chairing' the interviews.

In addition, given that I was a person of authority, the power imbalance between the participants and me may have influenced the way in which the participants responded, especially in the focus group interviews (Creswell, 2014; Goodwin and Goodwin, 2013; Shields and Rangarjan, 2013). To reduce this effect, I tried to create a relaxed and informal atmosphere. For example, the participants were welcomed at the door with a friendly smile and invited to sit in chairs forming a semi-circle (without tables) and then I joined them.

3.2.7.2 Bias due to Age Differential

Several studies have suggested that the age difference between the interviewer and the interviewees can potentially affect how the latter respond or behave in a focus group interview (Wilcox, 2017; Newton and Shaw, 2014; Goodwin and Goodwin, 2013). Since I was considerably older than the participants in the study, it may have had a bearing on their responses and behaviour. There was little that I could do about this other than make the participants feel as comfortable as possible by creating a friendly and welcoming environment.

3.2.7.3 Hawthorne Effect

Another potential source of bias relates to the Hawthorne Effect (HE). This states that when someone is taken out of their normal routine and interviewed or tested, it can affect their behaviour or responses (Goodwin and Goodwin, 2013; Shields and Rangarjan, 2013; Flick, 2009). For example, the participants who took part in my study were taken out of their scheduled lessons in order to be tested or interviewed by me. The resulting novelty and excitement may have influenced their subsequent responses or behaviours. To reduce any potential bias arising from the Hawthorne Effect, I encouraged the participants to do their best in the cognitive tests and to be as frank and open as possible when completing the questionnaire and in focus group interviews (if selected). I also made the purpose of my research clear from the outset and assured the participants that their responses would be treated in the strictest confidence.

3.2.7.4 Social Desirability Bias

Social Desirability Bias (SDB) relates to an individual's proclivity to conform to social and cultural norms (Goodwin and Goodwin, 2013; Flick, 2009; Bassey, 1999). In my study, SDB may have particularly influenced how some individuals behaved in the focus group interviews. For example, given the desire to conform, a participant may have agreed with others that physics lessons were boring and difficult even though secretly the participant may have found them engaging and challenging in a positive way. To reduce this possibility, I reminded the participants to express their views openly and freely, both when completing the questionnaire and during focus group interviews (if selected).

3.2.7.5 Location Bias

Location bias relates to how the immediate surroundings can potentially influence the responses and behaviours of the participants (Wilcox, 2017;

Russell, 2014; Goodwin and Goodwin, 2013). For example, in this study the data were collected on school premises. For some students, the latter may represent a formal and authoritarian environment, and this may have had a bearing on the way in which they responded, for example when completing the attitude questionnaire. However, given that these were school age participants it was not possible to conduct the research anywhere else because of safeguarding concerns.

3.2.7.6 Ethical Dimension

The ethical aspects of the investigation were extremely important, especially given that school age participants were involved in the study. Therefore, prior to the collection of the raw data, permission was secured from the following individuals: -

- Head Teacher
- Parent/Guardian/Primary Carer
- Participant

In addition, to ensure that the research adhered strictly to the guidelines issued by the University of Huddersfield and the British Educational Research Association (BERA), the participants were: -

- Made aware of the purpose of the study.
- Fully briefed about their role in the research.
- Assured that the information they provide will be treated as confidential.

- Given the option to opt out if selected.
- Allowed access to their data if requested.
- Given the option to withdraw from the study at any time.
- Informed that they would not be academically disadvantaged by taking part in the research.
- Not compelled to provide information of any kind.

(Adapted from BERA, 2011: Guidelines on Ethical Research)

The participants were also informed that their personal details would be anonymized and treated in the strictest confidence (Shields and Ranjargan, 2013; Adams and Cox, 2008; Macfarlane, 2008).

3.2.8 Conclusion

This chapter focused on the research design that was used to investigate the impact on GCSE grades in physics from three individual level cognitive-affective variables respectively. To that end, two standard tests were used to measure WMC and VSA respectively and AP were surveyed via questionnaire and then followed up by focus group interviews in order to deepen understanding regarding their development. The GCSE physics grades of the participants in the study were obtained from the two schools who took part in the study. SPSS provided the statistical tools that were used to analyse the quantitative data (from the questionnaire and from the two tests). Thematic Analysis (TA) was used to analyse the qualitative data (from the focus group interviews). The benefits and drawbacks of using TA were also discussed at length. In addition, the advantages and disadvantages of opportunistic sampling and random probability sampling were also discussed in detail. The effects from common types of bias on the present research were also identified and the steps taken to minimise their potentially harmful effects on the integrity of the research were discussed. Finally, ethical considerations and their impact on the present study were reviewed.

3.3.1 Introduction to Part III: Data Collection Instruments

This section represents the third segment of the Research Methodology and Methods chapter and covers the principal data collection instruments used in the study. The reasons for choosing these data collection instruments, including their perceived benefits and drawbacks are also covered in this section. In addition, the lessons learned from piloting these data collection instruments are discussed in some depth. The chapter also includes a brief profile of the two schools involved in the study. A summary of the key points addressed in the main body of this section is also included.

3.3.2 Measurement of Working Memory Capacity

The Digit Span Backwards Test (DSBT) that I used to measure the WMC of the participants in my study is largely derived from the work of Miller (1956) who pioneered research in the field of cognitive psychology; the full version of the test can be found in Appendix 1. The DSBT is frequently used to measure the WMC of an individual (Sorqvist et al., 2013; Wilhelm et al., 2013; Chu, 2008). For example, Nalliah (2012) used the DSBT when investigating the correlation between Academic Attainment and the WMC of final year medical students. In another example, Onwumere (2009) used the test to gauge the WMC of the participants as part of broader investigation. The aforesaid researcher was particularly interested in exploring the correlation between WMC and GCSE grades in mathematics.

There appear to be two important reasons behind the widespread usage of this test. Firstly, as we shall find out shortly, the test is relatively straightforward to administer and complete. Secondly, and more importantly, the test is deemed to be very reliable given that it has a Pearson-r linear correlation (test-retest) value of 0.8+. Normally, a quantitative data collection instrument with a Pearson-r value of 0.7+ is regarded as highly reliable (Fiske and Taylor, 2013; Wilhelm et al., 2013; Woods et al., 2011).

3.3.2.1 Procedure for Applying Digit Span Backwards Test

The procedure that I used to administer the DSBT in the larger study was adopted directly from that used by Nalliah, (2012) and Onwumere, (2009). To begin with, I read aloud 4 digits (in the range 1 to 9) at a rate of one digit per second once only. After the last digit had been read out, the participants were given 5 seconds to write down these digits in reverse order on the test sheet. For example, after reading out the numbers 4897, the participants were given 5 seconds to write them down in reverse order on the test sheet. The process was repeated with one exception; at the beginning of each new cycle an extra digit was added. The cycle stopped after 10 digits had been read aloud. Prior to carrying out the test, I did a practice 'run' with the participants in order to further clarify what was required of them.

3.3.2.2 Scoring the Digit Span Backwards Test (DSBT)

To ensure consistency when marking the DSBT, each script was scored using the method prescribed by Nalliah, (2012) and Onwumere, (2009). For example, if the participants correctly wrote six digits in reverse order but failed with the seventh, their WMC was deemed to be six. Thus, the WMC was fixed at the point at which the participant could no longer correctly write down the digits in reverse order (Nalliah, 2012; Onwumere, 2009).

3.3.2.3 Limitations of the Digit Span Backwards Test (DSBT)

The four digit randomly generated numbers in the DSBT had to be carefully checked beforehand to make sure they did not correspond with a well-known event, such as the start of World War II in 1939 for example. This could have given an unfair advantage to anyone familiar with this date and potentially compromised the integrity of the test (Nalliah, 2012; Onwumere, 2009).

3.3.2.4 Piloting Digit Span Backwards Test (DSBT)

Before employing the DSBT in the larger study, it was piloted beforehand. This proved extremely useful for two important reasons. Firstly, it became clear that some of the participants thought that the DSBT was a mathematics test. Secondly, it became apparent that I had underestimated the time needed to analyse the subsequent data. Consequently, when it came to the larger study, the participants were further reassured that this was not a mathematics test and the time set aside for analysing the data was revised upwards. In addition, I also completed the DSBT to gain some first-hand experience. I found the test relatively straightforward to complete. The next section outlines the approach used to assess the VSA of the participants in the study.

3.3.3 Testing Visual Spatial Ability (VSA)

The Purdue Spatial Visualization Test: of Rotations (PSVT: R) was selected to measure the VSA of the participants in my study and can be found in Appendix 2. The PSVT: R is an updated version of the Mental Rotations Test (MRT) originally developed by Guay (1980, 1977) for the purpose of measuring VSA (Levine et al., 2016; Xu et al., 2016; Kelly et al., 2014). The updated version was developed by Yoon (2011) who agreed that I could use it in my research. Unfortunately, it was not possible to pilot the PSVT: R because permission to use the test was obtained after the pilot phase of my study had concluded. However, I took the test myself and found it quite challenging but relatively easy to follow.

Since its inception, the PSVT: R has been widely used in the field of cognitive research for measuring VSA (Ernst et al., 2016; Thompson et al., 2013; Doyle et al., 2013). Indeed, it has featured in many studies investigating the association between VSA and attainment in STEM (Science, Technology, Engineering and Mathematics) as noted by Maeda and Yoon (2016): -

> '...the instrument [PSVT: R] has predominantly been used in science, technology, engineering, and mathematics (STEM) education research investigating the association between the spatial ability and STEM performance of students (Maeda and Yoon, 2016: Abstract).

For example, Thompson et al., (2013), used the test to measure the VSA of the participants when investigating the relationship between VSA and GCSE grades in mathematics (as part of a wider study). They used the test because of its very high reliability index (Pearson-r of 0.8+) coupled with its uncomplicated and easy to follow layout (Thompson et al., 2013).

3.3.3.1 PSVT: R Format and Marking Procedure

The test is made up of 30 questions; each question is worth one mark. The first 13 questions comprise symmetrical isometric shapes and the remainder comprise non-symmetrical isometric shapes. An isometric shape is a graphical representation of a 3-D shape on a sheet of paper. The participants were presented with a shape plus 5 rotated versions of this shape. However, only one of these rotated shapes exactly matched the original shape. The participants had to apply their visual spatial processing skills to identify the rotated shape that exactly matched the original shape. Furthermore, the questions on the test were graded in terms of difficulty with each question placing a greater demand on visual spatial processing ability compared to the previous question. The test was strictly timed at 20 minutes and the participants were not expected to complete the whole test in the allotted time. The participants were awarded one mark every time they selected the correctly rotated shape. The marks were then added to give a total mark for the test. The next section explains how I gauged the participants' AP.

3.3.4 Measuring Attitudes

How can an attitude toward something be measured in an effective and efficient manner? The literature suggests that when it comes to measuring '…attitude…surveys have emerged…as one of the most popular and commonplace approaches…' (Denscombe, 2007:7). However, for a survey to gauge an overall attitude accurately, it needs a valid, reliable and coherent questionnaire since 'The heart of a survey is its questionnaire' (Krosnick and Presser, 2010:263). Moreover, several studies have used questionnaires when investigating the attitudes of school age students towards physics, especially female students (IoP, 2012; Olusola and Rotimi, 2012; Francisco, 2010).

3.3.4.1 Attitude Questionnaire

The questionnaire employed in this study to assess the attitudes of the participants towards physics was developed by Hoyles et al., (2011); the full questionnaire can be found in Appendix 3. These authors specifically designed the questionnaire to survey (as part of a much wider study) the attitudes of Key Stage 4 students towards GCSE physics in England. Indeed, in his opening written address to potential participants, Reiss et al., (2011) makes the purpose of the questionnaire very clear, 'We are asking you questions...about...your attitudes to Physics' (Reiss et al., 2011:1). After obtaining permission from the authors, I used this questionnaire verbatim to gauge the AP of the participants in my study.

3.3.4.2 Seven Point Likert Scale

The questionnaire uses an interval scale arranged on a six-point Likert Scale. The response to each item or question is denoted by a number (1 to

6) ranging from Strongly Agree to Strongly Disagree. Some sections of the questionnaire also include a 'Cannot Say' option; this response was recorded as zero since it was deemed to be a neutral response. The authors of the questionnaire argue that the 'Cannot Say' options allow for a more truthful response; it means that the respondents are not forced to pick the alternative options which may not fairly reflect their position or viewpoint pertaining to a particular item on the questionnaire. In addition, the interval scale has the following attributes: -

- It is a quantitative scale which means that the data can be analysed using statistical tools.
- It measures items that exist along a common scale comprising equal intervals
- The difference between the numbers (for example between 1 and 2) is meaningful.

(Adapted from Stadler, 2015 and Macionis, 2012)

3.3.4.3 Scoring Attitudes

The positively worded questions or items on the questionnaire were scored differently from negatively worded items. This is shown in Table 1 below: -

Table 1: Method for Scoring Attitudes

Positively Worded Items on Questionnaire	Negatively Worded Items on Questionnaire
Strongly Agree = 6	Strongly Agree = 1
Agree = 5	Agree = 2
Slightly Agree = 4	Slightly Agree = 3
Slightly Disagree = 3	Slightly Disagree = 4
Disagree = 2	Disagree = 5
Strongly Disagree = 1	Strongly Disagree = 6

3.3.5 Findings from the Pilot Study

Piloting the questionnaire revealed that despite giving what I thought were clear-cut instructions, some of the participants were still unsure about how to complete the questionnaire. Consequently, in the larger study, I went through the example below to back-up my instructions.

	Strongly	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly
Students should be allowed to make personal calls on their mobile phones during a lesson	☐	☐	☐	☐	☐	☐

The participants were invited to read the question carefully and then asked which box they would tick. They were then told that all the items and statements on the questionnaire should be answered in the same way, that is, by ticking the box that most closely matched or reflected their personal feelings or views. In the pilot study, it also transpired that one participant had an auditory impairment and was assisted by a Learning Support Assistant (LSA). It quickly became apparent that had the LSA been informed beforehand, the member of staff would have been able to offer more support to the student. This case highlighted the wider issue of how best to assist any student with Special Educational Needs (SEN) if selected to take part in the study. It was decided that if a student with SEN was selected then the LSA attached to that student would be fully briefed beforehand.

3.3.6 Drawbacks of the Attitude Questionnaire

Arguably, the major drawback of using a questionnaire relates to the possibility that the participants may interpret the items in unintended ways (Brandt and Wetherell, 2012; Cooper, 2012; Gill and Bell, 2011). If that happens, it can potentially undermine the credibility of the data (Gross and Kinnison, 2014; Pallant, 2013; Knabe, 2012). It was difficult to guard against this possibility. However, by circulating amongst the participants (both in the pilot study and in the main study) I was able to deal with simple queries. For example, a student asked me to read an item on the questionnaire to him. Another student had placed the tick in the wrong box by mistake and asked me what to do and so on. The next section discusses how the qualitative data on AP was gleaned via focus group interviews.

3.3.7 Focus Group Interviews

Two focus group interviews were carried out, one at each school; each focus group was made up of 5 students. The latter were randomly selected from the students who had taken part in the questionnaire-based AP survey. The focus group interviews were carried out in order to gain a deeper understanding of the key factors contributing toward the development of AP.

The topics for discussion were generated after analysing the quantitative data obtained from the questionnaires. The Focus Group Interview Schedule in Appendix 4 includes the full topic list.

The focus group interviews lasted approximately 20 minutes and were carried out at each school on separate occasions. The aforesaid time limit was set by the senior management team (at each school); they did not want their students 'off-timetable' for too long given that they were preparing for their GCSE examinations. The focus group interviews were also taped with the express permission of the key stakeholders including the participants.

Focus group interviews were chosen for three important reasons. Firstly, given that they represent a '...a conversation with a purpose...' (McCleskey and Yallen, 2009:31) meant that I could '...find out what is in somebody else's mind' (Bush, 2007:94). Thus, they afforded me the opportunity to explore the underlying reasons why the participants responded in particular ways on the questionnaire. They also allowed me to delve more deeply into issues emerging from the interview process itself. Secondly, it gave the participants the opportunity to elaborate and express their views more clearly compared to the questionnaire. Thirdly, although one-to-one interviews would have provided broadly similar opportunities, the reason for choosing focus group interviews relates to the child-safeguarding dimension. The latter discourages one-to-one interviews between an adult and a school age child (Adams and Cox, 2008; Macfarlane, 2008; Ribbons, 2007).

3.3.7.1 Piloting the Focus Group Interviews

Taking on board the advice from Adams and Cox (2008) who recommend 'Piloting studies…to improve…interview techniques' (Adams and Cox: 2008:25), a pilot focus group interview was carried out beforehand. This proved extremely useful in allowing me to practise and refine the skills needed to manage a focus group effectively. It helped me to develop the competencies listed below that were later used in the main study: -

- Establishing basic ground rules, including the right of every participant to express a view or offer an opinion.
- Developing strategies to deal with interruptions and distractions.
- Experience in guiding the discussion back to the topic in hand and avoiding forays into areas of little interest to the study.
- Mining rich veins of information connected to the development of attitudes towards physics.
- Experience in maintaining the interest and engagement levels of the participants and to keep the discussion flowing.
- Confirming and summarizing the key points from the focus group session with the participants.

3.3.7.2 Drawbacks of Focus Group Interviews

A focus group interview has some potential disadvantages and those deemed particularly important are discussed now. A potential problem with a focus group interview is that more vocal participants may overwhelm the process and discourage others from offering their views. To avoid this happening, I encouraged everyone to express their views. In addition, some participants may be reluctant to express their views openly, perhaps because their views are at odds with those expressed by others. Again, I encouraged everyone to express their views openly and frankly. This aspect is discussed in more detail later in this section. Moreover, only around 6 topics could be covered in each focus group interview in the allotted time. This is because focus group interviews normally sacrifice scope in favour of depth of understanding as was the case in my study (Newby, 2010; Flick, 2008; Kvale, 2008).

3.3.8 Information about the Participants

The students who took part in my research attended two state funded schools and were at Key Stage 4 (Year 11) in the education cycle. They followed the AQA syllabus and were studying for the GCSE in Additional Science. The assessed elements comprising this award are shown in Table 2 below (AQA, 2015; JCQ, 2015).

Table 2: GCSE in Additional Science Grading Structure

Component Subject	GCSE Science (Additional) Examined Units	Pass Grade (Descending Order of Merit)
Physics	P1 and P2	A* to G
Chemistry	C1 and C2	A* to G
Biology	B1 and B2	A* to G

Those following the aforesaid route receive two grades at GCSE level in science; these can range from A*A* to GG (AQA, 2015). The GCSE grades in physics of the participants who took part in my study were provided by each school several weeks after the completion of the summer examination cycle in 2015. A short profile of the two schools that took part in my study is given below.

3.3.8.1 Profile of School-A

This is a large state funded secondary teaching establishment in Bradford. It caters for the educational needs of approximately 1,700 mixed gender students (aged 11 – 18). The students hail from a predominantly white British working-class socio-economic background. The number of students eligible for the pupil premium is above the national average for this school. The pupil premium is a grant awarded to schools by the government to help improve the overall attainment level of students deemed as being economically or socially disadvantaged. The school, which is recognized as a centre of excellence for Sports Technology was assessed by Ofsted2013 as 'requiring improvement' (Ofsted, 2013: Executive Summary).

3.3.8.2 Profile of School-B

This is a moderate sized secondary teaching establishment in Bradford catering for the educational needs of approximately 1,100 mixed gender students (aged 11 – 18). The students largely hail from a low to middle class socio-economic background. Compared to national Figures for England, the school has an above average proportion of students whose parents have Pakistani and Bangladeshi origins and consequently the number of students who speak English as a second language is above the national average. The proportion of students eligible for the pupil premium is broadly in line with the national average. The Institute is an approved centre for teacher training and was graded by Ofsted as good in 2015 (Ofsted, 2015; Executive Summary).

In 2015, about 90% of the students from school-A and about 80% of the students from school-B (in the second year of KS4) were entered for the GCSE in Additional Science with the AQA examination board. In the case of school-A, the units comprising chemistry, biology and physics (see Table 2) were taught in two blocks; approximately four teaching weeks were allocated to each block. With respect to school-B the aforesaid units were taught over a six-week cycle. Two experienced science teachers (at each school) delivered the learning units. Moreover, both schools set aside part of the academic year for revision purposes and for 'mock' summative assessments.

3.3.9 Conclusion

This section represented the third instalment of the overall chapter on Research Methodology and Methods. It focused on the data collection instruments that were used in my study. To that end, the WMC of the participants was assessed using the DSBT and their VSA was measured using the PSVT: R. In order to gauge their AP, I used a questionnaire designed specifically for that purpose by Hoyles et al., (2011). In addition, two focus group interviews were carried out to gain a deeper understanding of the factors behind the development of their AP. The benefits and drawbacks associated with each data collection instrument, as well as the justification for using them, were also discussed. Moreover, the ways in which the lessons learned from piloting these data collection instruments impacted the main data collection process were also addressed in this section. The next chapter spotlights the outcomes from the correlational analysis.

Chapter 4 Searching for Correlation

4.1 Introduction

As part of the key aim of my study, I investigated the nature and strength of the correlation between GCSE grades in physics and two individual level cognitive variables, namely WMC and VSA respectively; this chapter presents the findings from this dimension of my research. It also discusses how these findings expand knowledge and understanding in the field of physics education. The chapter begins by showing the mean and Standard Deviation (SD) of the GCSE grades in physics of the participants from each school; the mean values are then compared using Cohen’s d. Similarly, the SD values are also compared; this is done in order to understand the variability within and between the two datasets. The aforesaid steps are then repeated when comparing the mean and SD of WMC and VSA respectively. The quantitative data pertaining to the aforesaid variables are available upon request.

The chapter then breaks down into three parts. The first part explains how the PMCC (or r_s) was used to determine the strength of the linear correlation between GCSE grades in physics and the WMC and VSA of the participants respectively. It explains why the null hypothesis was rejected in favour of the alternative hypothesis (shown below in Table 3). The second part explains how the relationship between the aforesaid variables was modelled by way of the Multiple Regression Equation (MRE). The third part describes how the Confidence Intervals (CIs) were used to estimate the population parameters related to the mean GCSE grades in physics, WMC and VSA. In the context of my study, the term population refers to all Key Stage 4 (KS4) students attending state funded secondary schools in Bradford. Table 3 below provides a summary of the overall statistical approach that was used in this dimension of my research.

Table 3: Statistical Analysis Overview pertaining to WMC and VSA

Statistical Analysis	Statistical Tool
Descriptive Statistics Mean and SD of the GCSE grades in physics (school-A and school-B). Mean and SD of the WMC scores (school-A and school-B). Mean and SD of the VSA scores (school-B only). Purpose: To test the homogeneity of the data within and between the two datasets pertaining to the aforesaid variables.	Mean was taken as a measure of central tendency and SD was taken as a measure of dispersion. Cohen's d was used to determine if the difference between the mean values was statistically significant.
Tested the Null Hypothesis H_o: There is no correlation between GCSE grades in physics and WMC and VSA respectively. H_1: There is a correlation between GCSE grades in physics and WMC and VSA respectively. Purpose: To determine if there were sufficient grounds to reject the null hypothesis (H_o) in favour of the alternative hypothesis (H_1).	Calculated the PMCC (or r_s) for $p < 0.05$ level of significance.
Established the MRE for GCSE grades in physics and WMC, VSA and AP respectively. Purpose: To model the relationship between GCSE grades in physics and the aforesaid variables.	Formulated the MRE and used MRA to interpret the MRE.
Established the CIs pertaining to the mean GCSE grades in physics, WMC and VSA respectively. Purpose: To use the CIs to estimate the population mean values related to the aforesaid variables.	Calculated the CIs by using the sample mean and sample SD pertaining to each of the aforesaid variables.

4.2 Mean and Standard Deviation (SD) of GCSE Grades in Physics

Table 4 shows the mean and SD of the GCSE grades in physics of the participants from each school.

Table 4: GCSE Grades in Physics

Institute	Mean GCSE Grade in Physics	Standard Deviation	Sample Size
School-A	4.24 (average grade D)	1.19 (2 DP)	45
School-B	4.73 (average grade C)	1.24 (2 DP)	55

The Ofqual (Office of Qualifications and Examiners Regulation, 2018) grading scale shown below was used to convert the GCSE grades in physics from letters to numbers.

Grading Conversion Scale Adapted from Ofqual (2018)

U = U G = 1 F = 2 E = 3 D = 4 C = 5 B = 6 A = 7 A* = 8

As shown in Table 4, the participants from school-B attained better overall grades in GCSE physics compared to those from school-A. When rounded to the nearest whole number, the participants from school-B achieved a grade C (on average) whereas those from school-A attained a grade D (on average). Interestingly these values broadly echo those released by the Department for Education (DfE, 2015). The secondary school league table for Bradford shows that (in relation to English Language and Mathematics), 43% of the students from school-A achieved grades A to Cand 56% of the students from school-B achieved a grade A to C in the 2015 GCSE summer examinations (DfE, 2015). This date corresponds to the period over which I collected the primary data for my research. Cohen's d value (0.4) suggests that the difference between the two mean grades in GCSE physics is only mildly significant (Field, 2014; Nolan and Heinzen, 2011). In addition, SD>1 for both schools; this shows that the GCSE grades in physics are widely dispersed.

4.2.1 Mean and SD of VSA scores

Table 5 summarizes the mean and SD of the VSA scores of the participants from school-B.

Table 5: Visual Spatial Ability (VSA) scores

Institute	Mean PSVT: R Score	Standard Deviation of PSVT: R Score	Sample Size
School-A	no data available	no data available	n = 45
School-B	13.51 (2 DP)	4.82 (2 DP)	n = 55

Table 5 shows the mean (13.51) and SD (4.82) pertaining to the VSA scores of the participants from school-B; these values broadly resonate with those reported in other studies (Maeda and Yoon, 2016; 2014; Maeda et al., 2013). For example, in a large study comprising over 2000 participants, Maeda and Yoon (2014) reported an SD value of 5.19 for the VSA scores of the participants in their study. They used the PSVT: R version of the Mental Rotation Test (MRT) to assess the VSA of the participants (as I did in my study). Interestingly the mean VSA score (22.24) reported in their study was larger than that revealed by my study (13.51); however, Cohen's d value (0.35) suggests that the difference is only mildly significant (Field, 2014; Nolan and Heinzen, 2011).In addition, the mean VSA score (13.51) revealed by my study falls inside the range of VSA scores reported by other studies that have used the MRT (Newcombe and Levine, 2015; Tsui et al., 2014; Maeda and Yoon, 2013; Uttal and Cohen, 2012). Given that I was not able to assess the VSA of the participants from school-A, it was not possible to make a more meaningful comparison.

4.2.2 Mean and SD of WMC scores

Table 6 below summarizes the mean and SD of the WMC scores of the participants from each school.

Table 6: Working Memory Capacity (WMC) scores

Institute	Mean WMC Score	Standard Deviation of WMC Scores	Sample Size
School-A	5.53 (2 DP)	0.81 (2 DP)	n = 45
School-B	4.67 (2 DP)	1.02 (2 DP)	n = 55

Table 6 shows that, on average, the participants from school-A had a higher WMC compared to those from school-B. Moreover, Cohen's d value of 0.92 suggests that this difference is statistically significant (Field, 2013; Nolan and Heinzen, 2011). After rounding to the nearest whole number (which is common practice when reporting WMC), the average WMC scores are as follows: -

- Average WMC score = 6 (+/-1) of the participants from school-A
- Average WMC score = 5 (+/-1) of the participants from school-B

In practical terms these values suggest that, on average participants from school-A should be able to remember between 5 and 7 digits and those from school-B should be able to remember between 4 and 6 digits. However, 7 +/-2 is the frequently quoted value for the average WMC of an individual, aged 15 and above and chosen randomly from the wider population (Barrouillet and Camos, 2014; Broadway and Engle, 2010; Unsworth and Engle, 2007; Miller, 1956). This value was first identified by Miller (1956) and since then it has been confirmed on countless occasions. For example, Redick et al., (2012) confirmed this value (7+/- 2) after analysing secondary data related to the WMC of 6274 participants (aged between 17 and 35). Their analysis was based on data collected from multiple studies that had used automated versions of the Complex Span Test (CST) to assess WMC; I used the paper based DSBT version of the CST to assess the WMC of my participants. Clearly, the average value for WMC revealed by my study falls slightly below that generally reported in the wider literature. There may be two important reasons to account for the minor difference.

Firstly, I used two relatively small samples ($n_{sch\ A}$ =45 and $n_{sch\ B}$=55). In quantitative research, outcomes derived from a small sample may be less accurate and less reliable compared to those gleaned from a large sample (Field, 2014, Nolan and Heinzen, 2011). This is because a small sample (n < 100 for example) is less likely to be representative of the wider population from which it was drawn (Field, 2014; Nolan and Heinzen, 2011). In addition, a small sample has a large Standard Error of the Mean (SEM) and is more strongly affected by random and systematic errors (Field, 2014; Nolan and Heinzen, 2011). Thus, the fact that I used two relatively small samples may explain why the average values for WMC (5 +/-1 and 6 +/-1) revealed by my study are slightly below the average WMC value (7 +/-2) commonly reported in the wider literature.

Secondly, some academics in the field of educational psychology argue that the type of CST used to assess WMC may also influence the outcome. For example, I used the DSBT because the '...reversed digit span test…DSBT has been validated…as a measure of all the main components of WMC...' (Nalliah, 2012:92). In brief, participants had to listen carefully to a list of numbers (from 1 to 9) that were read out to them randomly; they then had to write these numbers down in reverse order.

However, in other versions of the CST (such as the Digit Span Forwards Test or DSFT), participants only must remember the digits in the order they are given; there is no need to write them down in reverse order (Chen and Cowen, 2009; Nalliah, 2009; Saults and Cowan, 2007). Consequently, this version of the test might give a slightly higher average value of WMC because the participants can concentrate full-on remembering the numbers in the order that they are given; they do not have to set aside part of their WMC to manipulate the data (Bowden, 2013; Schroeder, 2012; Reid, 2009b; Onwumere, 2009). This reason may also account for the difference between the average WMC revealed by my study and that generally reported in the wider literature. Moreover, SD ≈1; this shows that the spread in the WMC scores is relatively small (Field, 2014; Nolan and Heinzen, 2011).

4.3 GCSE Grades in Physics versus WMC scores

The Product Moment Correlation Coefficient (PMCC or r_s) was used to determine the strength of the linear correlation between GCSE grades in physics and the WMC scores of the participants sampled from each school; Table 7 reveals the outcomes from the analysis.

Table 7: GCSE Grades in Physics and WMC scores

Institute	GCSE grades in physics versus Working Memory Capacity (WMC) scores	Sample Size
School-A	r_s = 0.33 (2 DP)	n = 45
School-B	r_s = 0.28 (2 DP)	n = 55

4.3.1 Nature and Strength of the Correlation

The r_s values shown in Table 7 show a weak to moderate linear correlation between GCSE grades in physics and the WMC scores of the participants from each school. The criteria used to gauge the strength of the positive linear correlation are given below: -

- r_s values in the range 0.20 and 0.39 suggest a weak to moderate linear correlation between two variables
- r_s values in the range 0.40 to 0.59 suggest a moderate to strong linear correlation between two variables
- r_s values in the range 0.60 to 0.79 suggest a strong linear correlation between two variables
- r_s values 0.8 and above suggest a very strong linear correlation between two variables

Several studies have used these criteria when determining the strength of the linear correlation between two variables in educational psychology (Alloway et al., 2013; Hussein and Reid, 2009; Gathercole and Alloway, 2008; Evans, 1996).

4.3.2 Testing Null Hypotheses

The critical values of r_s beyond which we can reject H_o (null hypothesis) in favour of H_1 (alternative hypothesis) are given below: -

- Reject H_o in favour of H_1 if $r_s > 0.27$ (2 DP) at the 0.05 level of significance for a sample size between 40 and 49 (in a one tailed test); the sample size from school-A ($n_{schA}=45$) falls inside this range.
- Reject H_o in favour of H_1 if the critical value $r_s > 0.25$ (2 DP) at the 0.05 level of significance for a sample size between 50 and 59 (in a one tailed test); the sample size from school-B ($n_{schB}=55$) falls inside this range.

(Adapted from Wilcox, 2017 and Nachmias and Guerrero, 2014)

As shown in Table 7, the r_s values were higher than the critical values and this made it possible to reject the null hypothesis (H_o) in favour of the alternative hypothesis (H_1); there is a positive linear correlation between GCSE grades in physics and WMC and VSA respectively. Interestingly, the weak to moderate positive correlation between GCSE grades in physics and WMC resonates with numerous studies that report a positive linear correlation between AA in STEM subjects and WMC (Alloway et al., 2013; Gathercole and Alloway, 2008; Ali-Hamed, 2013; Holmes, 2012; Conway et al., 2007).

For example, Danili and Reid (2004) investigated the effects of WMC (amongst other variables) on AA in secondary school chemistry. They used a version of the CST to measure the WMC of 105 students (aged 15 to 16) in Greece. AA in chemistry was based on the students' grades in the National

Examinations in Secondary Education (NESE); the NESE broadly equates to the GCSE. After carefully analysing the data, they concluded that: -

> ‘A relationship exists between working memory capacity and pupils’ performance. This was shown in terms of a statistically…significant correlation (r = 0.31) …high working memory capacity pupils performed better in the chemistry test than intermediate working…memory capacity pupils, and intermediate working…memory capacity pupils performed better in chemistry test than low working…memory capacity counterparts’ (Danili and Reid, 2004:219).

In another study, Al-Enezi (2008) investigated the effects of WMC on AA in mathematics of 874 students (aged 14 to 15) in Kuwait. Al-Enezi (2008) used a version of the CST to measure WMC and based AA in mathematics on the intermediate level examination. The latter broadly examines learning material delivered in the first year of the two-year GCSE course in mathematics. Al-Enezi (2008) found a positive correlation (of moderate strength, r=0.36) between AA in mathematics and WMC. These studies illustrate how the findings from my research chime with others in the wider literature pointing to a positive linear correlation between AA in STEM subjects and WMC. Indeed, after carefully reviewing the published literature in this area of educational psychology, Solaz-Portolez and Sanjose-Lopez, (2009) concluded that, ‘Studies on...working memory capacity... support for the positive relationship between working memory capacity and science achievement’ (Solaz-Portolez and Sanjose-Lopez, 2009:82).

In finding a weak to moderate correlation between GCSE grades in physics and WMC, my research strengthens the generalization alluded to by Solaz-Portolez and Sanjose-Lopez, (2009), namely that AA in STEM subjects is influenced by the individual level cognitive factor related to WMC. Moreover, it potentially provides an opportunity for improving GCSE grades in physics by targeting WMC and VSA; this aspect of my research is discussed in greater depth in section 4.7.

4.4 GCSE Grades in Physics versus VSA scores

The PMCC (or r_s) was used to investigate the strength of the linear correlation between GCSE grades in physics and the VSA of the participants from school-B only. I was unable to assess the participants' VSA from school-A because the head teacher at this school felt that too much time had already been spent on carrying out the WMC tests and surveying the students' AP. Consequently, the head teacher reversed the previous decision, and I was not allowed to complete the VSA tests. Table 8 reveals the outcomes from the analysis.

Table 8: GCSE Grades in Physics versus VSA scores

Institute	Visual Spatial Ability (VSA) versus GCSE grades in physics
School-A	no data available
School-B	r_s = 0.44 (2 DP)

The r_s value of 0.44 shows a moderate to strong linear correlation between GCSE grades in physics and VSA; this value broadly resonates with those reported in other studies. Typically, these studies report a positive correlation (ranging from moderate to strong) between AA in STEM subjects and VSA scores (Kris, 2016; Andersen, 2014; Goodchild et al., 2014; Tosto et al., 2014).

For example, Yoon and Min (2016) investigated the influence of VSA on academic performance in atmospheric science (meteorology). They used the PSVT: R to assess the VSA of 119 students on the introductory course at a college in mid-western USA. Interestingly, only about a quarter of the students (23.9%) had post-16 qualifications in STEM subjects; the rest (76.1%) did not. After carefully analysing the data, Yoon and Min (2016) concluded that, 'The students' spatial ability had positive and significant relationships with all measures of their performance in the atmospheric science course' (Yoon and Min, 2016:418). In addition, the authors reported that students with post-16 qualifications in STEM subjects generally possessed stronger VSA and tended to attain better overall grades compared to other students on the course (Yoon and Min, 2016).

In another example, after carefully reviewing the published literature in this field, Harrison and Lubinksi (2013) reached the following conclusion: -

> 'For over 60 years, longitudinal research on tens of thousands of…youth has consistently revealed the importance of spatial ability for… the development of expertise in science, technology, engineering, and mathematical (STEM) disciplines (Harrison and Lubinksi: 2013: 219).

In finding a moderate to strong correlation between GCSE grades in physics and VSA, my study strengthens the generalization alluded to by Harrison and Lubinksi (2013), namely that AA in STEM subjects is influenced by individual level cognitive factor related to VSA. Moreover, it potentially provides an opportunity for improving GCSE grades in physics by targeting WMC and VSA. This aspect of my research is discussed in greater depth in section 4.7.

4.5 Confidence Interval

This section shows the Confidence Intervals (CIs) that were used to estimate the population parameters corresponding to average WMC and VSA. In my study, the population refers to all KS4 students attending state funded secondary schools in Bradford. Moreover, given that the CIs were estimated at the 95% level of significance, we can be reasonably confident that they contain the aforesaid population parameters (Field, 2014; Nolan and Heinzen, 2011). Table 9 summarizes the CIs related to the aforesaid variables.

Table 9: Confidence Interval (CI) for mean WMC and VSA scores

Confidence Interval (CI) at 95% Confidence Level	School-A	School-B
CI for the mean WMC scores	CI = 5.29, 5.77 CI size = 5.77 – 5.29 = 0.48	CI=4.40, 4.94 CI size = 4.94 – 4.4 = 0.54
CI for the mean VSA scores	no data available	CI = 12.24, 14.78 CI size = 14.78 - 12.24 = 2.54

4.5.1 CI for the mean WMC scores

The CIs corresponding to WMC are shown in Table 9; the CIs indicate that we should expect the average WMC of the population to be between 4 and 7 units. However, since the two CIs do not overlap, we must choose between them (Field, 2014, Noland and Heinzen, 2011). Under these circumstances, the sample with the smaller CI size is generally regarded as providing a better estimate of the unknown population parameter, in this case the mean WMC of the population from which these two samples were drawn (Field, 2014; Nolan and Heinzen, 2011). Thus, the CI calculated for school-A (range 0.48) is preferred over that of school-B (range 0.54). The average value for WMC (between 5 and 7 units) is slightly below that reported in other studies (between 5 and 9); the potential reasons behind this difference were discussed in section 4.2.2.

4.5.2 CI for the mean VSA scores

The CI corresponding to VSA is shown in Table 9; the CI indicates that we should expect the average VSA of the population to be between 12 and 15 units. The aforesaid range broadly resonates with that reported in other studies. For example, Maeda and Yoon (2013) reviewed the findings from 40 studies to better understand the relationship between VSA and gender; these studies employed the same test that I used to assess VSA, namely the PSVT: R. After reviewing these studies, Maeda and Yoon (2013) reported the mean VSA score to range between 10 and 22; my values fit inside this range.

4.6 Original Contribution

In finding a positive linear correlation between GCSE grades in physics and VSA and WMC respectively, my study has strengthened the generalization arguably alluded to in the wider literature that AA in STEM subjects is influenced by these two individual level cognitive factors. Moreover, when the aforesaid correlation is viewed alongside mounting evidence (from other studies) suggesting that WMC and VSA can be improved or enhanced through mental training, it opens the possibility of improving overall GCSE grades in physics by targeting WMC and VSA. Importantly, the latter may also bolster interest in post-16 physics.

4.7 Conclusion

As part of my overall aims, I investigated the relationship between GCSE grades in physics and two individual level cognitive variables namely, WMC and VSA. In doing so: -

- I identified a positive linear correlation between GCSE grades in physics and WMC and VSA respectively.
- I calculated the MRE to model the relationship between GCSE grades in physics and WMC and VSA respectively.
- I calculated the CIs to estimate the population parameters related to average WMC and VSA at the 95% level of confidence.

I then discussed the strong possibility of raising overall attainment in GCSE physics by improving or enhancing WMC and VSA through mental training. The next chapter presents the theoretical framework that I used to explain the positive correlation between GCSE grades in physics and WMC and VSA respectively.

Chapter 5 Information Processing Theory (IPT)

5.1 Introduction

This chapter uses IPT to advance a post hoc explanation to potentially account for the correlation between GCSE grades in physics and two individual level cognitive variables namely, WMC and VSA. The nature and strength of the correlation between the aforesaid variables was discussed in Chapter 4. The approach is novel in the sense that there is a dearth of studies in the field of physics education that have applied a coherent theoretical perspective to explain why the aforesaid cognitive variables influence AA in physics; my study bridged this perceived gap in knowledge and understanding.

The chapter begins by spotlighting the core tenets that underpin IPT. It explains how the latter places memory at the centre of operations when it comes to processing or making sense of information. The chapter then focuses on the Working Memory Model (WMM). Grounded in IPT, the latter is used to describe and explain the cognitive functions related to WMC and VSA. The WMM is then used to explain the critical role played by the aforesaid variables when it comes to learning and understanding.

5.2 Information Processing Theory (IPT)

The human brain is a remarkable organ; it is difficult not to feel a sense of awe when we consider the myriad functions under its control. These range from coordinating our body movements when we are awake to regulating our breathing when we are asleep. However, little was known about the inner workings of the brain and more especially the cognitive processes involved in learning or sense making. In my study, learning or sense making is defined as, 'A process that leads to change, which occurs as a result of experience and increases the potential for improved performance and future learning' (Ambrose et al, 2010:3). Over time, cognitive psychologists began formulating theories to describe and explain the mental processes behind human cognition (Miller, 2011; Halpern, 2003). Out of the milieu of competing ideas emerged a set of cognitive theories embedded in the information processing paradigm (Taylor, 2013; Öztekin et al., 2008).

Arguably, the most influential member of this family (particularly in the field of educational psychology) is Information Processing Theory (IPT) which came into prominence in the 1950's (Miller, 2011; Reid, 2009; Cassino et al., 2007). At its core, IPT contends that the way in which humans process or make sense of information is comparable to the way in which a conventional computer processes data. Thus, advocates of IPT contend that 'Information processing in humans resembles that in computers' (Mcleod, 2008:3). The basic features shared by both the computer and the human brain are summarized in Table 10 below.

Table 10: Comparing Human Cognitive Processes with Computer Functions

Comparator	Raw Data Input into Sensory Memory (SM)	Processing of Raw Data	Processed or Modified Data
Computer	Example: Electronic information inputted via keyboard	Central Processing Unit (CPU)	Saved electronically in the permanent storage facility
Human Brain	Example: Audio verbal or visual spatial information inputted from sensory organs	Neural Network (NN) Comprising Working Memory (WM)	Saved organically in Long Term Memory (LTM)

(Adapted from Saeki et al., 2013)

From Table 10 we note how the conventional computer receives information electronically into Sensory Memory (SM) from an input device. Similarly, the brain receives information (audio verbal for example) into SM from its sensory organs. The Central Processing Unit (CPU) systematically transforms or alters the incoming information via electronic processing (Yang et al., 2015; Nemes, 2011; Orey, 2010). Correspondingly, the Neural Network (NN) comprising WM systematically alters the incoming information through cognitive processing (Sigel and Sapru, 2015; Taylor, 2013). The computer stores the processed information electronically in the permanent storage facility (internal hard drive for example); the brain stores the processed information organically in Long Term Memory (LTM). The processed information can be retrieved from the permanent storage facility or LTM if needed (Baddeley et al, 2014; Saeki et al., 2013; Mcleod, 2008).

Table 10 shows how IPT places memory (SM, WM and LTM) at the centre of all cognitive processes. However, IPT also regards memory as a hypothetical construct with no physical dimensions; this means that memory cannot be observed or measured directly (Gross, 2012; Miller, 2011; Mcleod, 2008). Thus, 'when we talk about…" memory" …we are talking about something that is abstract…that cannot be …seen…touched' (Taylor, 2012:3).

Interestingly, research from the emerging field of neuropsychology appears to have identified regions of the brain ostensibly linked to memory (Siegel and Sapru, 2015; Yang et al., 2015). For example, images taken using neuroimaging 'cameras' appear to show specific parts of the brain becoming activated or 'lighting-up' when creating, storing or retrieving memory (Siegel and Sapru, 2015).

However, these findings are far from conclusive and advocates of IPT (including myself) continue to hold the position that memory is a hypothetical construct (Taylor, 2013; Henry, 2012; Miller, 2011; Gables and Birney, 2009). This position is aptly summarized by Taylor (2013) as follows: 'There is no way to look inside the brain and see some specific activity indicating that this thing we call memory has occurred' (Taylor, 2013: 24-25). The nature and function of the individual memory elements is discussed next.

5.2.1 Sensory Memory (SM) and the Perception Filter (PF)

The information received through our sensory organs is temporarily held in Sensory Memory (SM). This is also referred to as the Sensory Register (SR) and represents the first memory element in the information processing chain (Öztekin et al., 2008; Cassino et al, 2007). Although the capacity of SM is thought to be almost limitless, in practice SM normally processes only a small fraction of the information that it receives as noted by Chu (2008): -

> '…the...brain constantly receives a huge amount of information inputs through the five senses, but only a fraction of them can be noticed or handled at any one time and then transferred to the next stage of the memory system '(Chu:2008:60).

The average adult can accommodate and process between 12 and 22 items of information; any unprocessed information leaks away from SM and is lost in a few seconds (Johnstone, 2006). Importantly, the information we process largely depends on whether we regard it as important or worthy of attention (Siegel and Sapru, 2015; Taylor, 2013; Chu, 2008). Exactly how we decide the importance of the incoming information is still the subject of some debate (Woolfolk, 2014, 2007; Gross, 2012; Baddeley, 2010).

From the standpoint of IPT, perception plays a large part in determining whether we ignore or pay attention to the incoming information (Miller, 2011; Orey, 2010; Mcleod, 2008; Johnstone, 2006). In particular, the Perception Filter (PF) helps us determine the relative value or importance of the incoming information (White, 2012; Johnstone; 2010, 1997; Betz, 2006). Although the PF is closely related to SM, they are generally regarded as separate memory elements (White, 2012; Johnstone; 2010, 1997; Betz, 2006). Figure 5 below shows the SM and the PF alongside the other principal components comprising memory architecture.

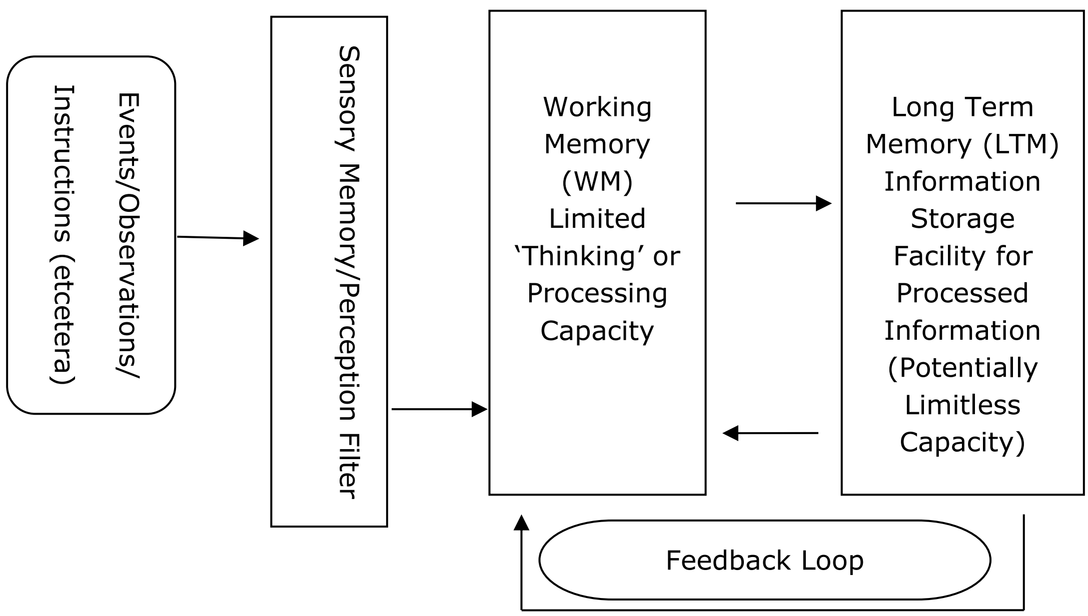


Figure 5: Information Processing Architecture
(Adapted from Johnstone, 1997)

From the perspective of IPT, the SM is bombarded with visual spatial, auditory and kinaesthetic information from the external environment (Barrouillet and Camos, 2014; Saeki et al., 2013; Johnstone, 2010).

However, the PF only allows information deemed important or worthy of attention to pass to the next element in the cognitive processing chain, namely Working Memory or WM (Baddeley, 2010; Woolfolk, 2007 and Johnstone, 2006). A simple but effective explanation of the primary function of the PF is provided by White (2012) as follows: -

> 'When we walk down a street, we may see many faces, but we ignore almost all of them. Unless we are purposefully looking for someone, only the occasional face will impinge on our consciousness...These are examples of our perception filter at work. Our perception filter operates in all realms of our consciousness' (White, 2012:138).

Moreover, the PF is part of a large feedback loop; this means that it is influenced by the other memory elements shown in Figure 5. Thus: -

> '...what we pay attention to is guided...by what we already know and what we need to know, so attention is involved in and influenced by all three memory processes' (Woolfolk: 2007:252).

The presence of the feedback loop means that all three memory components are interdependent and strongly influence each other when processing information (Woolfolk, 2007).

The explanations proffered by Woolfolk (2007) and White (2012) summarize complex theoretical arguments, ideas and concepts comprising IPT in a concrete and accessible way. After being acknowledged and accepted in SM, the information is then encoded in readiness for further cognitive processing.

5.2.2 Encoding

Encoding involves converting information from the outside world (verbal for example) into a form that can be processed and transformed into different kinds of memory, especially LTM. There are four principal types of encoding, namely visual, acoustic and semantic (Alloway and Copello, 2013).

5.2.2.1 Visual Encoding and Iconic Memory

Visual Encoding (VE) involves the processing of visual sensory information. Creating mental images (or pictures) of visual spatial stimuli represents an important dimension of VE (Pratt, 2018; Ogmen and Herzog, 2016; Alloway and Copello, 2013). In relation to learning physics for example, VE can be very effective in helping us to remember words such as, 'push', 'pull' and 'accelerate'. This is because most of us can associate strong imagery with these words and this can help us to store and retrieve them from LTM. However, VE can be less effective in storing and retrieving words or phrases such as 'refraction', 'electromagnetic induction' and 'voltage'; these relate to abstract concepts and are generally more difficult to visualize mentally.

As part of the VE process, the visual sensory information is temporarily stored within Iconic Memory (IM) before being transferred to LTM. Iconic Memory (IM) is a type of SM which can retain visual sensory information for a short period of time. Moreover, the image contained within IM continues to persist even after the stimulus that gave rise to it has ceased (Pratt, 2018; Ogmen and Herzog, 2016). In relation to learning physics for example, IM can help us to recollect how a metal wire placed between the poles of a horseshoe magnet suddenly (and briefly) jumped or moved when an electrical current passed through it. Although IM is believed to possess a relatively large cognitive capacity, any information not transferred into LTM tends to fade away rapidly, usually after a few hundred milliseconds (Pratt, 2018; Ogmen and Herzog, 2016).

5.2.2.2 Acoustic Encoding

Acousting Encoding (AE) involves creating memory by processing and encoding sounds, words and related auditory information. This also includes using our 'inner voice' to rehearse or repeat information in order to create new memories or reinforce existing memories in LTM (Mandler, 2013; Daniel and Tversky, 2012). In relation to learning physics for example, we can use 'flash cards' to memorize important facts about the nature of electromagnetic waves. 'Flash cards' normally have a prompt on one side and the relevant information on the other side. Ideally working in pairs, one individual reads out loud the prompt and the other person vocalizes the response by recalling the relevant information from LTM.

5.2.2.3 Semantic Encoding

Semantic Encoding involves creating or strengthening LTM memory through mental association (Ogmen and Herzog, 2016; Mandler, 2013; Daniel and Tversky, 2012). For example, you might remember your favourite fruit by its colour, or a phone number based on the person's name. In relation to learning physics for example, most of us can associate the word 'gravity' with a falling object (such as a book falling from a shelf). In semantic encoding therefore, the meaning or context of the word, picture, concept, phrase or event (etcetera) is encoded and then transferred into LTM (Ogmen and Herzog, 2016; Mandler, 2013; Daniel and Tversky, 2012).

5.2.3 Long Term Memory (LTM)

Long Term Memory (LTM) is where processed information is permanently stored and from where it can be retrieved if needed. Thus, LTM contains skills, knowledge, experience and understanding that we have accumulated over the years (Nemes, 2011; Baddeley, 2010). Theoretically, the LTM has unlimited storage capacity, and we ought to be able to retrieve (or remember) everything stored in this vast database (Nemes, 2011; Unsworth and Spillers, 2010; Reid, 2009). The LTM is made up of three subcomponents, namely episodic memory, semantic memory and procedural memory; these are outlined next.

5.2.3.1 Episodic Memory (EM)

Episodic Memory (EM) represents our recollection of specific (and usually important) events that took place at a particular moment in our lives. These events are stored in LTM as visual spatial representations or mental images (Baddeley et al., 2014; Unsworth et al., 2009). In addition, EM is tagged with our subjective experience of it, and this is reflected in the way we reconstruct or remember it (Ogmen and Herzog, 2016; Mandler, 2013; Daniel and Tversky, 2012). Examples of EM include where and when you drank alcohol for the first time (and how that made you feel) or the day you passed your driving test (and the emotions associated with that event). In relation to learning physics, EM can help us to recall an equation to solve a problem in a test or examination. For example, we may recall the equation by remembering the first time we applied it successfully to solve a problem. EM is also a form of declarative memory; this means that we must consciously recall the specific event from our LTM (Ogmen and Herzog, 2016; Mandler, 2013; Daniel and Tversky, 2012).

5.2.3.2 Semantic Memory (SM)

Semantic Memory (SM) is a type of LTM and comprises knowledge and understanding about the world that we have accumulated over the years (Unsworth and Spillers 2010, Unsworth et al., 2009). Educational psychologists also regard semantic memory as a form of declarative or explicit memory because we are consciously aware of the facts, ideas, concepts and meanings contained within it. Moreover, the information stored in semantic memory is not grounded in a specific location, time or social setting – it is context free (Unsworth and Spillers 2010, Unsworth et al., 2009). Moreover, SE can be used to label and categorize information and dovetail freshly processed information with existing information.

Examples of semantic memory include knowing that the sky is blue or that tennis is a sport. Examples related to physics include knowing that an object can accelerate when pushed or pulled or that metals conduct electricity. However, semantic memory is not simply a collection of disparate pieces of factual knowledge. Semantic memory links facts, ideas and concepts together in a web-like fashion known as the semantic network (Unsworth and Spillers 2010, Unsworth et al., 2009). The latter facilitates deeper learning and understanding; examples include recognizing that energy and mass are related ($E = mc^2$) or that electricity comprises tiny particles called electrons. Thus, from the standpoint of IPT and the WMM, semantic memory represents an important component of the overall memory architecture.

5.2.3.3 Procedural Memory (PM)

Procedural Memory (PM) represents the ability to perform certain tasks automatically, especially those that involve motor skills or motor actions (Lee et al., 2013). For example, swimming or cycling largely relies on PM; those of us who know how to swim, and cycle can perform these tasks without being directly aware of how we are doing them. Thus, procedural memories can be stored and retrieved (or triggered) without the need for conscious control or attention (Shaki and Gevers, 2011; Frith, 2008). In relation to learning physics for example, PM can help us to set-up and perform an experiment with which we are well acquainted.

5.3 Working Memory Model (WMM)

The Working Memory Model (WMM) proposed by Baddeley and Hitch (1974) is widely acknowledged as the dominant model for explaining the cognitive functions linked to learning or sense making (Allen et al., 2014; Weisberg and Reeves, 2013; Schuler et al., 2011). The model is of special interest to my research for two primary reasons. Firstly, it potentially explains the role that WMC and VSA play in processing or making sense of information (Barrouillet and Camos, 2015; Baddeley et al, 2014; 2010; Debue and Leemput, 2014). Secondly, in conjunction with IPT, the model provides a powerful theoretical framework which we can use to potentially explain the positive linear correlation between GCSE grades in physics and WMC and VSA respectively.

At its core, the model asserts that: -

> ‘Working memory can be conceptualized as a thinking–holding space. It can be seen as that part of the brain where incoming information is placed temporarily. It is where thinking, interpreting, understanding and problem-solving takes place...’ (Hindal et al., 2009:190).

Thus, Working Memory (WM) performs two distinct functions simultaneously; part of it holds a small quantity of unprocessed information

(7 +/- 2 units on average) for a short time (typically 10 to 15 seconds) and the remaining part then processes or makes sense of that information (Galy et al., 2012; Kalyuga, 2011). A unit of unprocessed information can include a digit, letter, word or phrase (Johnstone, 2010; Baddeley, 2000).

5.3.1 Working Memory (WM) Architecture

The main components that make up the WMM are shown below in Figure 6.

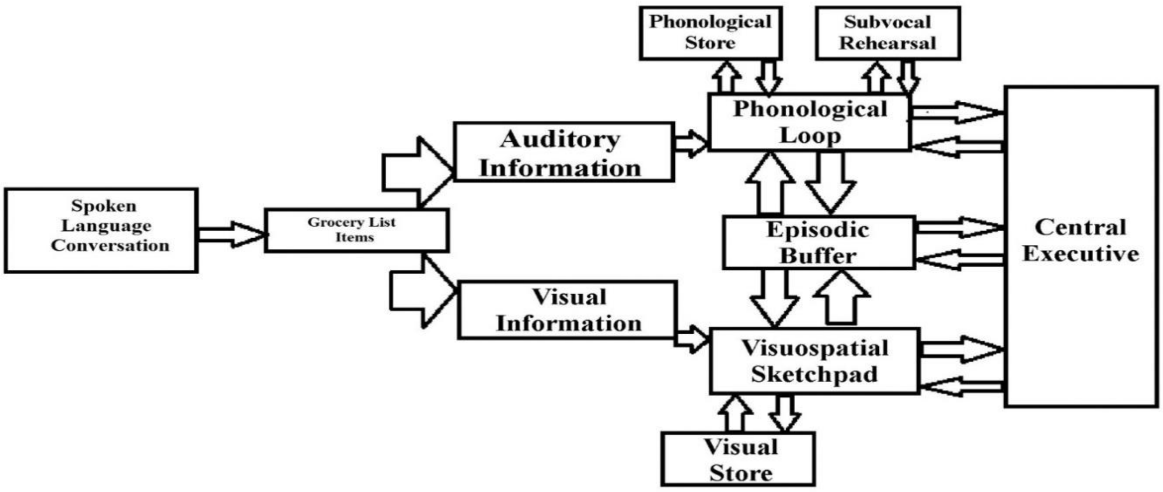


Figure 6: Working Memory Model
(Adapted from Baddeley and Hitch, 1974)

As shown in Figure 6, the Working Memory Model (WMM) largely focuses on explaining how we process auditory and visual spatial information; importantly the latter represents the VSA component of WMC (Bielski and Lansing, 2012; Henry, 2012; Taylor, 2012). Consequently, when discussing the correlation between GCSE grades in physics and WMC and VSA we are in effect discussing the correlation between GCSE grades in physics and WMC and its visual spatial processing component namely, VSA. The nature and function of the primary elements that make up the WMM are discussed next.

5.3.2 Central Executive (CE)

The Central Executive (CE) represents a critical component of the WMM; it plays a central role in the creation, storage and retrieval of memory. In turn, memory (especially in the guise of WM) provides us with many of our cognitive skills and abilities; examples include learning, reflecting, understanding, decision-making and problem solving (Taylor, 2012; Baddeley, 2010; Gathercole and Alloway, 2007).

The CE is also responsible for carrying out other cognitive tasks; these include closely monitoring the exchange of information between the various memory elements. Toggling between cognitive processes allows the CE to coordinate, monitor and control their actions. Indeed, such is the extent of its versatility and flexibility that if there is a problem in any of the myriad mental processes, the CE can intervene and make the necessary corrections and adjustments (Baddeley, 2010; Colom et al., 2008; Baddeley and Hitch, 1974). The ability to switch between cognitive tasks represents a powerful feature of the CE. Moreover, the CE can also collect and collate processed information from the other memory elements, and this makes it easier to integrate freshly processed information with that already stored in LTM (Weisberg and Reeves, 2013; Taylor, 2012; Baddeley, 2007). In addition, the CE is responsible for focusing our attention on information deemed to be important while simultaneously suppressing or inhibiting information considered to be unimportant (Weisberg and Reeves, 2013; Taylor, 2012). In this way, the CE helps us to make the best possible use of our limited cognitive resources when processing or making sense of information (Taylor, 2012; Gathercole and Alloway, 2007).

The CE is also largely responsible for the type of information that tends to attract our attention. In the context of learning physics, this means that some learners will tend to focus on visual spatial information (for example, a graph showing the relationship between voltage and current); others will tend to pay more attention to auditory information (for example, listening to the teacher explain the relationship between voltage and current). Thus, although both auditory and visual spatial information is registered in WM and undergoes processing, one type receives more consideration or attention than the other (Henry 2012; Taylor, 2012). Some educational psychologists refer to this as preferred cognitive learning styles and classify individuals as primarily visual spatial, auditory or kinaesthetic learners (Estes and Felker, 2011; Bracey, 2008; Zimmer, 2008). However, the idea that individuals have preferred cognitive learning styles is still keenly debated in the field of educational psychology and largely resides outside the remit of my study.

To help accomplish its multiple duties and responsibilities, the CE enlists the aid of three slave subsystems, namely the Phonological Loop (PL), Visual spatial Sketch Pad (VSSP) and the Episodic Buffer (EB). Each performs a specific function and is always under the direct control of the CE (Daniel and Tyerksy, 2012; Estes and Felker, 2011; Baddeley, 2007). Thus, the CE may be regarded as an orchestra conductor marshalling the ensemble of disparate musical instruments (metaphor for mental processes) in order to create pleasing music (metaphor for learning or understanding). The next section considers the role of the slave subsystems in much greater depth; it begins with the Phonological Loop (PL).

5.3.3 Phonological Loop (PL)

The Phonological Loop (PL) is chiefly responsible for processing or making sense of auditory and verbal information (Weisberg and Reeves 2013). Figure 7 provides a visual representation of the PL.

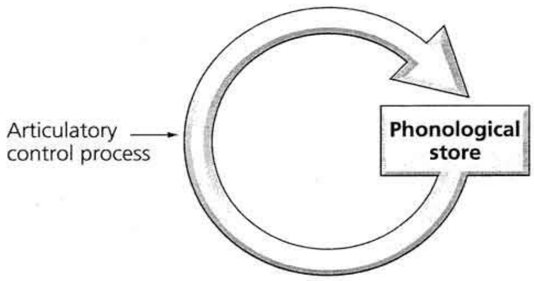


Figure 7: Phonological Loop
(Adapted from Baddeley et al., 2010)

When someone speaks, our Phonological Loop (PL) becomes active and remains active until the person stops speaking (Bracey, 2008). The spoken information is then stored and processed in the auditory component of the WM shown in Figure 7. Without this cognitive ability, it would be very difficult to learn or make sense of information. Imagine the disruption to learning if we could not remember the words spoken by the teacher at the start of the sentence long enough to link them to the words at the end of the sentence. Similarly, imagine how difficult it would be to make sense of a written sentence if we could not remember the beginning of the sentence after reaching the end of the sentence; the PL helps reduce the likelihood of either event (Holly and Allyson, 2013; Diezmann and Lowrie, 2012; Schuler et al., 2011). The PL comprises two subcomponents and these are spotlighted next.

5.3.4 Phonological Store (PS)

The Phonological Store (PS) helps the PL to process auditory and verbal information more effectively and efficiently (Mualem and Eylon, 2007; Angell et al, 2004). In particular, the PS plays a key role in perceiving speech and in processing language. Spoken words like “voltage” and “current” are stored directly in the PS whereas written material such as ‘voltage is proportional to current in an ohmic device’ must be converted into an articulatory (or spoken code) before entering the PS; this aspect is discussed in more depth in the next section. Unfortunately, unless it is repeated or rehearsed regularly, information can only be held in the PS for a few seconds before leaking away; the PS also has limited processing capacity (Ashcroft and Moore, 2009; Ogunleye, 2009).

Given the limited capacity of the PS, the nature of the auditory and verbal material strongly influences how much of it can be stored and processed (Saeki, et al., 2013; Bracey, 2008; Owens et al., 2008). For example, making sense of the words ‘push’ and ‘pull’ is relatively straightforward; they also take up less WMC. In contrast, the words ‘kinetic energy’ or ‘terminal velocity’ require more conceptual unpacking; they also take up more WMC. Without the assistance of the PS, our ability to process auditory and verbal information, especially of a more complex nature (as in the example above) would be greatly reduced (Holly and Allyson, 2013; Diezmann and Lowrie, 2012; Schuler et al., 2011).

5.3.5 Articulatory Control Process (ACP)

The Articulatory Control Process (ACP) is closely associated with the PS and is largely responsible for processing or making sense of information through mental rehearsal. To facilitate effective processing, the ACP converts written information into an articulatory (or spoken) form. The latter is then moved backwards and forwards between the ACP and the PS as part of the learning or sense making process (Saeki et al., 2013; Bracey, 2008; Bull and Epsy, 2006). The constant switching enables the information to remain active (or memorable) for longer. In this way, the ACP, '...refreshes…sounds and words through rehearsal, in order to prevent their loss...' (Weisberg and Reeves 2013:73-74). The overall effect can be likened to a physics student memorizing key facts about the different kinds of radiation from a physics textbook by vocalizing them. Bull and Epsy (2006) explain the importance of the ACP as follows: -

> 'Information held in the phonological store is subject to decay, unless it can be refreshed by...rehearsal, a process akin to repeating under one's breath the information one is trying to retain...' (Bull and Epsy, 2006:110).

Consequently, the more often we rehearse material verbally (imagine actors rehearsing their 'lines' for a play), the more likely we are to remember it (Baddeley et al., 2014). Without the assistance of the ACP, we would forget what we had learned or memorized relatively quickly (Taylor, 2012; Bull and Epsy, 2006).

5.3.6 Visual Spatial Sketch Pad (VSSP)

The Visual Spatial Sketch Pad (VSSP) is the primary agent behind our Visual Spatial Ability (VSA). Figure 8 below spotlights the primary function of the VSSP and shows the relationship between the VSSP and the other key components of the WMM.

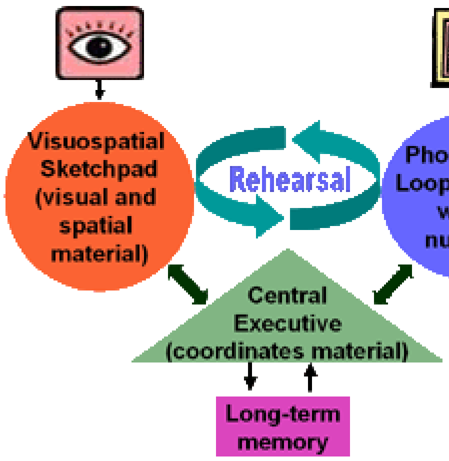


Figure 8: Visual Spatial Sketch Pad or VSSP
(Adapted from Walter, 2008)

The VSSP is mainly responsible for processing or making sense of visual spatial information (Weisberg and Reeves 2013; Estes and Felker 2011). The VSSP has a limited cognitive processing capacity and can normally hold visual spatial information for a few seconds (unless it is rehearsed regularly). The VSSP is made up of two independent visual spatial information processing subsystems and these are discussed next.

5.3.6.1 Visual Subsystem (VS)

The Visual Subsystem (or Visual Cache) is responsible for processing information related to the shape and colour of physical objects (Sorby et al., 2013; Kelly, 2012; Bracey, 2008). Examples of the VS in action include remembering the colour of your car or the shape of your house. In addition, it can help you recall the texture of different substances; examples include the roughness of sandpaper or the smoothness of a snooker ball (Estes and Felker, 2011). Moreover, the VS can also create pictorial or symbolic representations of real or imaginary phenomena. These representations can take several forms; examples include sketches, diagrams and mental maps (Diezmann and Lowrie, 2012; Schuler et al., 2011; Marschark et al., 2006). The ability to mentally visualize abstract ideas and concepts can be particularly useful when studying physics; this dimension of the discussion is covered in much greater depth in the next chapter.

5.3.6.2 Spatial Subsystem (SS)

The Spatial Subsystem (or Inner Scribe) is largely responsible for helping us to make sense of spatial information in 3-D; examples include interpreting the size and orientation of buildings or judging the speed of a car in the distance (Doyle, 2016; Marschark, 2015; Andersen, 2014).

Thus, the SS can be extremely useful in lots of ways, not least when navigating the physical landscape as noted by Baddeley (2006), one of the co-founders of the WMM, '...the…spatial system will play a crucial role in the acquisition of our…spatial knowledge of the world...such as... How can I find my way around my hometown?' (Baddeley, 2006:13).

In the context of learning physics, the SS can be extremely useful in several ways; for example, it can help us to manipulate equipment in order to carry out an experiment. When used in conjunction with the VS, it can also help us to interpret the outcomes from the experiment graphically and commit these to memory. It can also help us to create a pictorial representation of the outcomes; examples include noting how light rays striking a glass block (at an angle) bend or change direction after passing through or memorizing the shape of the magnetic field around a bar magnet. Recapping, the VSSP is chiefly responsible for our visual spatial information processing abilities (or VSA) as noted by Bruckner, (2013): -

> '…. visual spatial ability…a group of related skills...include the ability to generate visual images, perceive spatial arrangements, construct and deconstruct mental visual images, retain images in the mind, and transform, manipulate…images mentally…' (Bruckner, 2013:1).

Without VSA it would be very difficult to carry out many of the physical and cognitive activities that most of us take for granted. The next section considers the role of the Episodic Buffer (EB) in the WMM.

5.3.7 Episodic Buffer (EB)

The Episodic Buffer (EB) is the third slave system under the direct control of the CE. This limited capacity system is responsible for integrating (or binding together) information from the different working memory elements in chronologically ordered chunks called 'episodes' (Baddeley et al., 2010; 2000 Zimmer, 2008). The central function of the EB is neatly summarized by Weisberg and Reeves (2013) as follows: -

> 'The episodic buffer...brings together phonological, visual, spatial, and other relevant information...and this allows us to remember information we learned at a specific time...' (Weisberg and Reeves 2013:74).

Examples of the EB in action include helping us to recall where and when we bought our first home and how much it cost. In the context of learning physics, it can include recalling the first time we correctly solved a problem in mechanics using Newton's Laws of Motion. These events are episodic because the EB has arranged them in the order in which they happened in time and therefore episodic memory is autobiographical in nature (Tsui et al., 2014; Weisberg and Reeves, 2013). The EB can do this because it can synthesize information from the different memory components to form a holistic memory image or trace in time specific order (Barrouillet and Camos, 2015; Carbone II, 2009). It can be loosely compared to a television screen; just as auditory and visual spatial information is brought together on the television screen (imagine watching a film), similarly the auditory and visual spatial information held in the memory elements comprising WM are brought together in chronological order in the EB. Thus, with the help of the

EB we can recall or replay events in our personal history in the order they happened (Barrouillet and Camos, 2015; Carbone II, 2009). Recapping: -

> '...in the…model of working memory …a central executive directs attention during memory tasks… information is maintained either in the phonological loop (for verbally-oriented material) or a visuo-spatial sketchpad (for visually oriented material) … the episodic buffer… pulls together phonological and visual information… into a single memory…' (Weisberg and Reeves 2013:76).

Thus, most of our WMC is devoted to the processing of auditory and visual spatial information (Sorqvist et al., 2013; Wai et al., 2009; Sweller et al., 1998; Miller, 1956). In addition, WMC is strongly influenced by genetic factors; consequently, it shows considerable variation in the general population (Cowan, 2010; Holme and Adams, 2006).

5.4 Relationship between WM and WMC

Thus far we have established that '…a person's working memory…represents…a mental workspace that enables individuals to juggle several thoughts simultaneously' (Finn et al., 2014:736). Working Memory Capacity (WMC) represents the size of this '...mental workspace...' (Finn et al., 2014:736). Moreover, WMC attains its maximum size when we reach the age of about 15 and varies from person to person (Thomas et al., 2015; Goksun et al., 2013; Ishak et al 2012).

The terms WM and WMC are often used interchangeably in the field of educational psychology, and this can be confusing (Goksun et al., 2013; Daniel and Tversky, 2012; Cowan, 2005). In my study, WMC represents the maximum quantity of auditory and visual spatial information that WM can hold and process simultaneously (Hinojosa, 2015; Kelly, 2012; Hindal et al., 2009). Moreover, the capacity of the auditory component (shown in Figure 7) is generally taken to represent the WMC of the individual (Sorqvist et al., 2013; Woehrl and Magliano, 2012; Chu, 2008). The key techniques that can potentially be used to reduce cognitive load on WMC and VSA are discussed in the next section.

5.4.1 Chunking

From the standpoint of the WMM, chunking represents a conscious strategy to reduce cognitive load when processing information (Kirshner et al., 2011; Jainta and Baccino, 2010; Sweller, 2010). In effect, chunking allows us to capture, process and retain information (in both WM and LTM) more efficiently and effectively (Woehrl and Magliano, 2012; Oberauer et al., 2007; Kane et al., 2006). Chunking normally involves breaking information down into smaller pieces that can be processed and stored more easily (Levine et al., 2016; Kalyuga, 2011; Johnstone et al., 1998). Specifically, similarities or patterns are identified in the data and grouped into smaller meaningful units or chunks (Woehrl and Magliano, 2012; Oberauer et al., 2007; Miller, 1956). For example, we can reduce the cognitive processing load by chunking the postcode LS98AH as [LS9] [8AH]. We can also use part of a chunk (in WM) to trigger our LTM and remember the entire chunk; provided it has been stored in LTM in the first place (Kirshner et al., 2011; Jainta and Baccino, 2010; Sweller, 2010). For example, observing the motion of a boat on a choppy sea may help us to recall the properties of transverse waves. Recalling part of the electromagnetic spectrum may activate our LTM and help us remember the full spectrum.

5.4.1.1 Mnemonics and Mind Maps

Chunking strategies are strongly influenced by the scope and depth of learning that we are trying to achieve. For example, mnemonics can be very useful when it comes to rote learning. This is where new knowledge is only partially integrated with existing knowledge stored in LTM (Debue and Leemput, 2014; Khooshabeh et al., 2013; Sorby et al., 2013). By way of illustration, we can use the mnemonic Very Clever Relatives to memorize the relatively simple equation Voltage = Current x Resistance.

We can use mind maps to acquire deeper or more meaningful learning; this is where new knowledge and understanding is more fully integrated with the existing knowledge structure contained in LTM (Galy et al., 2012; Schuler et al., 2011; Hindal, 2007). This is largely because diagrams can be retained and processed more easily in WM compared to other representational formats. In particular, the information contained in a mind map can be encoded in both visual and written form at the same time (Levine et al., 2016; Johnstone et al., 1998). This means that mind maps can generally place less cognitive load on WMC compared to reading a long paragraph or listening to a lengthy lecture for example. In addition, they can be stored and retrieved more easily from LTM (Galy et al., 2012; Schuler et al., 2011; Hindal, 2007).

Recapping, we can use different types of chunking strategies to reduce the overall cognitive load on WMC and VSA. These strategies include making use of visual spatial imagery (mind maps for example) and retrieval cues (mnemonics for example). Thus, chunking allows us to create, store and retrieve memory (representing processed information) more efficiently and effectively (Galy et al., 2012; Schuler et al., 2011; Bracey, 2008). The next section reflects on the perceived strengths and weaknesses of the WMM in explaining the cognitive processes linked to learning or sense making.

5.5 Strengths of the Working Memory Model (WMM)

The literature review points to strong support for the WMM in explaining the cognitive processes linked to learning or sense making (Daniel and Tyersky, 2012; Wills, 2007). In particular, the WMM has been highly influential over the past few decades in informing and guiding empirical studies investigating cognitive disorders linked to learning, especially amongst school age children (Pathman and Bauer, 2013; Wilhelm et al., 2013; Moos and Stewart, 2012). Many of these studies suggest that deficits in specific functions associated with WM are largely responsible for various cognitive processing disorders. Examples include ADHD (Attention Deficit and Hyperactivity Disorder), arithmetic learning disability, dyslexia, language impairment and Autism Spectrum Disorder or ASD (Finn et al., 2014; Carbone II, 2009; Bull and Espy, 2006).

These studies report that individuals with learning difficulties are often unable to adequately process and integrate information in the memory system (as posited in the WMM). They generally attribute these problems to neuropsychological deficits in central executive functions related to WM; examples include the EB, ACP, PL, PS and the CE. This can lead to reading problems (e.g., poor comprehension); writing issues (e.g., spelling mistakes); difficulties in mathematics (e.g., weakness in mental arithmetic) and so on (Jaroslawka et al., 2016; Wang, 2015; Langerock, 2014; Unsworth and Engle, 2007).

For example, Moura et al., (2015) investigated the effects of deficits in phonological processing (including ACP, PL and PS) in children (aged 11 to 13) with developmental dyslexia. Specifically, 72 children were randomly selected and then divided into two cohorts; one cohort had developmental dyslexia and the other did not. The children in both cohorts: -

> '…were tested on measures of phonological processing (phonological awareness, naming speed and verbal short-term memory) and reading…The results indicated that the children with [developmental dyslexia] performed significantly poorer in all measures…' (Moura et al., 2015:60).

In another study, Kofler et al (2018) investigated the relationship between WM deficits and ADHD. Specifically, they randomly selected 86 children (aged 8 to 13) and placed them in two cohorts; one cohort had ADHD and the other did not. The students then: -

> '…completed three…working memory tests that were identical in all aspects … (phonological, visuospatial, episodic buffer) …ANOVAs indicated that the ADHD group performed significantly worse on all three working memory tests' (Kofler et al., 2018: 1171).

From these findings Kofler et al (2018) concluded that 'Working memory deficits are present in a substantial proportion of children with ADHD' (Kofler et al, 2018:1171).

Further evidence in support of IPT and the WMM comes from the field of neuroscience. It appears that '…neuroimaging research provides biological support to many of the findings in information processing theory' (Miller, 2011:320-321). For example, evidence from this field supports the idea of an EB as noted by Crossland (2010): -

> 'Recent fMRI [functional Magnetic Resonance Imaging] findings indicate that the medial temporal lobes of the neo-cortex play a crucial role in both long-term memory encoding, and working memory, indicating that they work together and therefore support the concept of an episodic buffer' (Crossland, 2010:107).

Given these strengths, it is not difficult to understand why the WMM continues to dominate the field of educational psychology. The next section reflects on the supposed key weaknesses of the WMM.

5.6 Weaknesses of the Working Memory Model (WMM)

Despite dominating the field of educational psychology for several years, the WMM has drawn criticism from some educational psychologists. The perceived weaknesses of the model appear to fall into four broad areas.

Firstly, a major criticism of the model is its apparent lack of clarity in explaining the precise features and functions of the CE (Eggen and Kauchack, 2007; Bull and Espy, 2006; Conway et al., 2006). Critics argue that '...the structure and functioning of the central executive remains underspecified in Baddeley's theory...' (Barrouillet and Camos 2015:136). For example, the model contends that the CE has limited capacity; however, it is not possible to measure the capacity of the CE because of the difficulties involved in isolating the CE from the other systems affiliated to it. In addition, given that the CE works closely with several subsystems, critics argue that it is not always clear which of these is responsible for what specific cognitive function. For example, they argue that it is difficult to distinguish between cognitive functions directly under the control of the CE from those under the control of the CE and one (or more) of its subsystems (Barrouillet and Camos, 2015; Lee et al., 2013;). Thus, the model's perceived vagueness in explaining the nature and function of the CE is regarded as a major weakness (Sorqvist et al., 2013; Dingfelder, 2005).

Secondly, others criticize the WMM for its perceived lack of ecological validity. They argue that the WMM relies almost entirely on data collected under strictly controlled conditions to explain the cognitive processes linked to learning and sense making. They argue that these data do not include the 'noisiness' and 'messiness' inherent in data from the real world (Contero et al., 2012; Ceci et al., 2009; Eggen and Kauchack, 2007). Consequently, critics contend that processing auditory and visual spatial information from the real world may be more complex and multifaceted than that advocated by the WMM (Frith 2008; Moore and Johnson, 2008; Eddens and Potter, 2007).

Many also challenge the model's contention that learning or sensemaking is akin to computational processing. Critics argue that '...unlike humans, computers do not…hug other computers' (Gibson, 2003:292); they point to growing evidence suggesting that our moods, feelings and emotions influence how effectively and efficiently we process information (Moos and Stewart, 2012; Frith 2008; Gibson, 2003). Frith (2008) crystallizes this counter argument as follows: 'In the 21st century, we are discovering more and more about the…role of emotion, on...how we learn…and remember' (Frith 2008:45).

These criticisms are difficult to ignore; for example, imagine trying to process or make sense of information when angry, worried or upset. A review of the published literature suggests that advocates of the WMM are largely silent over this issue. In addition, scholars and academics in the field of cognitive psychology are now challenging the model's assertion that genetic factors largely determine the size or capacity of WM (Alloway, 2014, 201; Harrison et al., 2013; Morrison and Chen, 2011). This is because of growing evidence suggesting that WMC and VSA can be improved or enhanced through mental training (D’Esposito and Postle, 2015; Alloway, et al., 2013). In the context of learning physics, improving WMC and VSA could be extremely beneficial; in particular, it would allow us to hold and process (or make sense of) more information (Alloway, 2014, 2012; Harrison et al., 2013; Morrison and Chen, 2011). In addition, there is further evidence to suggest that the additional cognitive processing power deepens learning and understanding (Harrison et al., 2013; Morrison and Chen, 2011).

Moreover, when evidence suggesting that WMC and VSA can be improved through mental training is viewed alongside the positive correlation identified by my study (between GCSE grades in physics and WMC and VSA) it opens the possibility of improving overall grades in GCSE physics by targeting WMC and VSA. This dimension of my study is discussed more fully in the next chapter. In its defence, advocates of the model point to numerous studies in the field of educational psychology that appear to confirm the outcomes predicted by the model (Foster et al., 2015; Enriquez-Ceppert et al., 2013; Elliot and Czarnolewski, 2007). They also point to evidence from the emerging field of neuropsychology which broadly appears to support the memory architecture proposed by the WMM (Shaki and Gevers, 2011; Frith, 2008). Thus, despite the perceived weak spots in the model’s theoretical framework, the latter remains at the cutting edge when it comes to explaining the cognitive processes involved in learning and understanding.

5.7 Conclusion

Information Processing Theory (IPT) is widely acknowledged by many educational psychologists as the dominant theory for explaining the cognitive functions associated with learning and understanding. At its core, the theory contends that the way in which we process or make sense of information is very similar to the way in which a conventional computer processes information. Thus, mental processes in the human brain are comparable to electronic processes in the computer. Moreover, from the standpoint of the WMM (derived from IPT) memory plays a crucial role when it comes to processing or making sense of auditory and visual spatial information. Even though the WMM dominates the field of educational psychology, critics argue that: -

- The model largely ignores the effects from affective factors on cognitive functions.
- The model does not fully explain the role of the Central Executive (CE) in the learning or sense making process.
- The model lacks ecological validity; its theoretical framework is mostly based on data collected under strictly controlled conditions.
- In asserting that WMC and VSA are primarily influenced by genetic factors, the model largely ignores growing evidence suggesting that mental training can improve or enhance WMC and VSA.

However, advocates of the WMM reject many of these criticisms by drawing attention to several studies (in the fields of cognitive psychology and neuropsychology) which broadly support the aforesaid model.

Finally, several studies have suggested that WMC and VSA can be improved through mental training. When viewed alongside the findings from my study, it opens the possibility of improving AA in physics by targeting these individual level cognitive factors. Next, the theoretical perspectives afforded by IPT and its derivative the WMM are used to explain the positive correlation between GCSE grades and WMC and VSA respectively.

Chapter 6 Explaining the Correlation

6.1 Introduction

This chapter explains why possessing a relatively large WMC and good VSA can be advantageous when studying physics from the perspective of IPT and its derivative the WMM. In particular, the chapter spotlights the heavy cognitive load that can be placed on WMC and VSA when studying physics; both from the abstract and concept-driven nature of physics and from the physics curriculum. The chapter then employs Cognitive Load Theory (CLT) to break down the specific types of cognitive load on WMC and VSA arising from studying physics at the secondary tier of education. CLT is firmly embedded in the information processing paradigm and closely entwined with IPT and the WMM. In addition, the chapter uses CLT to explain the adverse effects on learning physics if the total cognitive load exceeds the WMC and VSA of the individual. With the help of CLT, the chapter then discusses how the total cognitive load can be reduced when studying physics. The final section provides a summary of the key points addressed in the main body of the chapter.

6.2 Learning Physics and Cognitive Load

From the standpoint of IPT and the WMM it is expected that my study should find a positive linear correlation between GCSE grades in physics and WMC and VSA respectively. IPT contends that an individual with a relatively large WMC and good VSA can hold and process more information, (auditory and visual spatial for example) compared to someone with a more limited WMC and VSA (Jarrold et al., 2011; Hindal et al., 2009; Graham and Pegg, 2008; Schnotz and Kurshner, 2007). In effect, the individual who falls in the former category has a greater '...capacity…to perform complex tasks such as reasoning, comprehending and learning ', (Baddeley, 2010:136). Consequently, '...having a larger working memory…gives the learner an advantage in learning and assessment tasks' (Hindal et al., 2009:195). Moreover, possessing a relatively large WMC and good VSA can be especially advantageous when studying STEM subjects (Chuderski, 2012; Ishak et al., 2012; Best et al., 2011; Geake, 2006). This is because making sense of scientific ideas and concepts can place a heavy cognitive load on WMC and VSA as noted by Kapon, (2017): -

> 'Employing scientific ideas and models…involves a complex process of sense making in which a learner constructs and reconstructs a series of self-explanations that evolve, change, replace one another, or merge into a new self-explanation…the evolution of self-explanations involves an ongoing tacit evolution of their relative soundness.' (Kapon, 2017:178).

Given how physics is heavily laden with abstract ideas and concepts, the cognitive load on WMC and VSA can be very high. Hinojosa (2015) spotlights the size of this cognitive load as follows: -

> 'By learning physics, one acquires two different types of knowledge: general and specific. Specific knowledge is defined as rules about disciplines on how to handle specific situations. General knowledge is defined as applicable strategies for problem solving, inventive thinking, decision-making, learning, and good mental management. Physics is a discipline that is based on a specific type of knowledge skills that allow for one to learn about how the universe works…' (Hinojosa, 2015:65).

Moreover, many would argue that learning should ideally be deep and meaningful. Wiske (1998) regards deep and meaningful learning as '...the ability to think and act flexibly with what one knows . . . a flexible performance capability... as opposed to rote recall or "plugging in" of answers...', (Wiske, 1998:40). However, the acquisition of deeper and more meaningful learning can add to the existing cognitive load on WMC and VSA (Gulbinaiter et al., 2014; Khooshabeh et al., 2013; Engle et al., 1999). From the standpoint of IPT, an individual with a bigger cognitive processing capacity is more likely to accommodate the additional cognitive load. In the context of studying physics, signs of deep and meaningful learning may include using physics specific vocabulary to convey understanding, solving problems in physics using novel approaches and attaining consistently high grades in assessments and tests. The next section uses the theoretical perspectives afforded by Cognitive Load Theory (CLT) to expand and develop the aforesaid discussion further.

6.3 Cognitive Load Theory (CLT)

Cognitive Load Theory (CLT), initially developed by Sweller (et al., 1998) is firmly grounded in the information processing paradigm and closely entwined with IPT and the WMM. At its centre the theory contends that whenever we engage our mental faculties, for example when learning a new skill or solving a problem, we place a cognitive load on our WMC and VSA

(Taylor, 2013:62). The cognitive load can be broken down into three distinct types and expressed mathematically as follows: -

- 'Intrinsic + Germane + Extraneous = Total Cognitive Load' (Jalani and Lai, 2015:874).

The size of the cognitive load from each component in the equation above depends on the complexity of the cognitive task we are undertaking (Kwaja et al., 2014; Buettner, 2013; Paas and Sweller, 2012). Unfortunately, since '...the memory that a person has in order to accomplish a task is finite and limited...' (Hinojosa, 2015:14), the total cognitive load may exceed our cognitive processing capacity (Buettner, 2013; Paas and Sweller, 2012; Sweller et al., 2008). If that happens, it can seriously undermine the learning or sense making process. Alloway, (2006) explains this as follows: -

> '…the capacity of working memory is limited, and the imposition of either excess storage or processing demands in the course of an on-going cognitive activity will lead to catastrophic loss of information from this temporary memory system' (Alloway, 2006:134).

Thus, as the total cognitive load on WMC and VSA starts to build, it can become more difficult to process information efficiently and effectively (Owens et al., 2008; Reif et al., 2008). For example, our thinking may become muddled and confused or we may find it more difficult to mentally visualize and link concepts together (Breighthaupt and Calder, 2016; Ogunleye, 2009; Sweller et al., 1988).

Moreover, if the total cognitive load surpasses our WMC and VSA, the learning or sense making process can almost completely stop (Breighthaupt and Calder, 2016; Foster et al., 2014; Taylor, 2013). In order to avoid this situation, advocates of CLT argue that we must strive to reduce the overall cognitive load on WMC and VSA as much as possible, '…the load on working memory needs to be minimized in each of these areas so that people can process information more effectively and learn better' (Sweller et al., 2011:54). In relation to '…these areas…' Sweller et al., (211:54) are referring to the three types of cognitive load comprising the cognitive load equation mentioned previously, namely Intrinsic Cognitive Load (ICL); Germane Cognitive Load (GCL) and Extraneous Cognitive Load (ECL). However, in the context of learning physics, reducing the cognitive load from each of these variables may not be simple or straightforward; we will begin the discussion by focusing on ICL.

6.3.1 Intrinsic Cognitive Load (ICL)

Intrinsic Cognitive Load (ICL) relates to the inherent complexity of the subject matter being studied and the extent of the individual's previous knowledge and understanding of that subject matter (Jalani and Lai, 2015; Kwaja et al., 2014; Sweller et al., 2011). We can view ICL in terms of learning elements (Owens et al., 2008; Mualem and Eylon, 2010; 2007; Angell et al, 2004). A learning element is '…anything that needs to be or has been learned, such as a concept or a procedure' (Sweller, 2010:124). These learning elements place varying degrees of cognitive load on WMC and VSA.

We will focus on the learning elements embedded in the physics curriculum; these are shown below: -

1. The use of models, as in the particle model of matter or the wave models of light and of sound.
2. The concept of cause and effect in explaining such links as those between force and acceleration, or between changes in atomic nuclei and radioactive emissions.
3. The phenomena of 'action at a distance' and the related concept of the field as the key to analysing electrical, magnetic and gravitational effects.
4. Differences between pressure, temperature or electrical potentials for example are the drivers of change.
5. That proportionality, for example between weight and mass of an object or between force and extension in a spring, is an important aspect of many models in science.
6. That physical laws and models are expressed in mathematical form.

(National Curriculum for Physics, 2015:33).

By way of illustration, part of learning element 4 expects students '...to recall that current (I) depends on both resistance (R) and potential difference (V) and the units in which these are measured...' (DfE, 2015:40). In general, memorizing these kinds of basic facts places a relatively low cognitive load on WMC and VSA. Learning element 4 also expects students

'...to... apply the relationship between I, R and V...' to solve problems (DfE, 2015:40). Problem solving generally requires more cognitive processing and this can place a relatively high cognitive load on WMC and VSA. Thus, WMC and VSA must cope with the varying degrees of cognitive load generated by the aforesaid learning elements. From the standpoint of IPT, an individual with a relatively bigger WMC and stronger VSA is much better placed to deal with these cognitive demands compared to an individual with a more finite WMC and weaker VSA (Baddeley et al., 2014; Taylor, 2013). In addition, the physics curriculum expects students to interweave multiple concepts at the same time; this can place an additional cognitive load on WMC and VSA. The extract below (which I have highlighted in certain parts) illustrates this point: -

> 'Physics is the science of the fundamental concepts of field, force, radiation and particle structures, which are **inter-linked** to form **unified models** of the behaviour of the material universe… Students should...understand how, through the ideas of physics, the complex and diverse phenomena of the natural world can be described in terms of... key ideas which are of universal application...this...sets out the...content for GCSE physics...' (DfE, 2015:33).

The nature of the cognitive load on WMC and VSA arising from this dimension of the physics curriculum is discussed in the next section.

6.3.1.1 Understanding Concepts in Physics

The conceptual triangle (shown below in Figure 9) was developed by Johnstone (2006) to explain why learning scientific concepts simultaneously can place a heavy cognitive load on WMC and VSA.

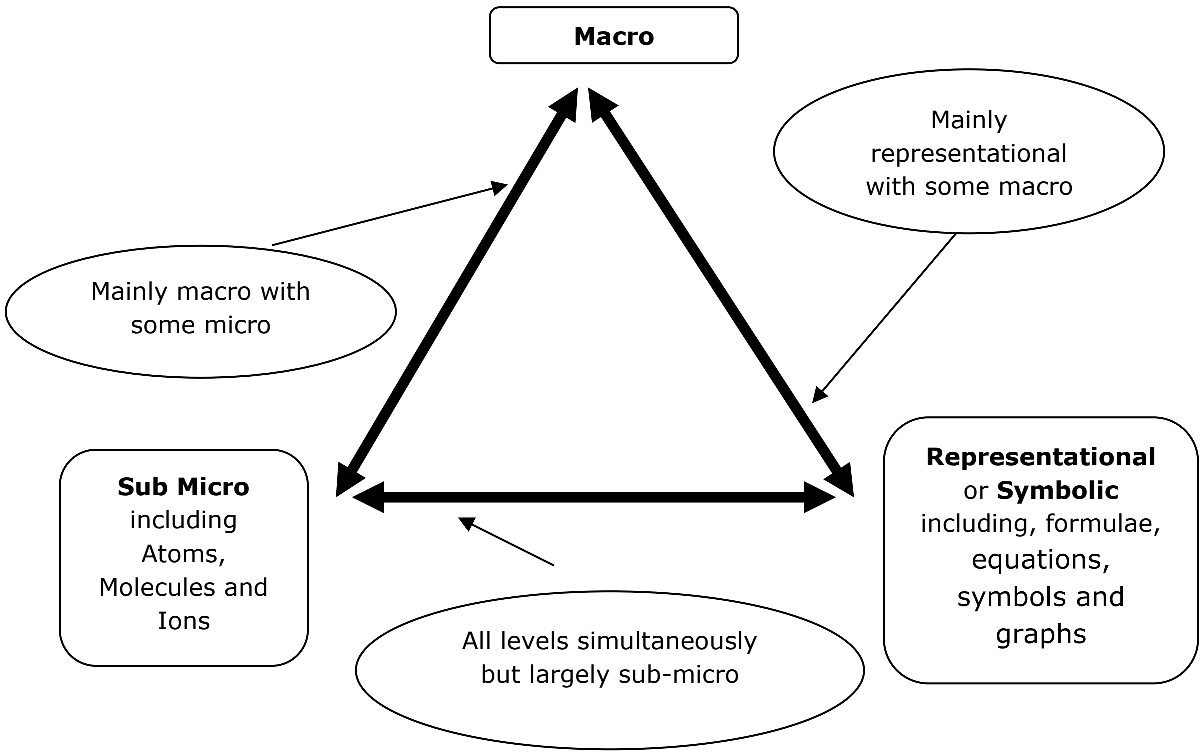


Figure 9: Conceptual Triangle
(Adapted from Johnstone, 2006)

Drawing on ideas firmly in CLT, Johnstone (2006) argues that when it comes to understanding concepts in chemistry, we must coordinate our thinking within (and along) the boundaries of the conceptual triangle at the same time. Although this can give '…us a powerful way of thinking about our discipline…' (Johnstone, 2006:59), it can also place an enormous cognitive load on WMC and VSA. Expanding further he writes: -

> 'In many lessons, there is a blend of all three experiences simultaneously, represented by a point within the triangle, its position being determined by the relative proportion of the three components. Inside the triangle lies the potential for gross overload of Working Memory Space' (Johnstone, 2006:59).

Thus, as we mentally navigate between the vertices of the conceptual triangle, we run the risk of saturating our cognitive processing capacity. If that happens, '...the system overloads and seizes up…' (Johnstone, 2006:56) and we end up learning a fraction of what we could have learnt had our WMC and VSA not become overloaded (Johnstone, 2006; 1997; 1991). Using a crude analogy, trying to think clearly when our cognitive processing capacity has been taxed to its limit is akin to eating a bowl of soup with a fork instead of a spoon; no matter how hard we try, very little goes in. Moreover, individuals with a relatively small cognitive processing capacity are more susceptible to cognitive overload (Odden, 2017; Vorstenbusch et al., 2013; Johnstone, 2006; 1997; 1991). Johnstone's (2006) conceptual triangle can also be broadly applied to physics; this is largely because abstract ideas and concepts feature strongly in both subjects. Table 11 below illustrates the close relationship between physics and chemistry at the secondary tier of education, namely KS4.

Table 11: Working with Concepts

Conceptual Level	Physics	Chemistry
Macro	Force; Wave Motion; Thermodynamics; Radioactivity; Electricity; Magnetism	Energy Changes; Organic Chemistry; Quantitative Chemistry; Chemical Analysis; Periodic Table
Representational	Mass of a substance = Volume x Density	Amount of a substance = Volume x Concentration
Sub micro	Atomic Structure and the Particle Model of Matter	Structure, Bonding and the Properties of Matter

(Adapted from the National Curriculum for Science DfE, 2015)

Moreover, at the representational level, in addition to formulae, other aspects of mathematics also feature strongly in both chemistry and physics; examples include graphs, sketches, figures and diagrams. This enhances the representational or symbolic component of Johnstone's (2006) conceptual triangle and adds to the cognitive load on WMC and VSA. Moreover, when I compared the mathematical content involved in learning chemistry and physics from the perspective of the science curriculum, it became clear that physics relied more heavily on mathematics. For example, the physics component of the science curriculum expects students to learn (and potentially apply) about 20 formulae at KS4; in chemistry it is less than half that number (DfE, 2015). In addition, students learning physics need to be especially proficient in the following areas: -

- Arithmetic and Numerical Computation
- Handling Data
- Algebra
- Graphs
- Geometry and Trigonometry

(Adapted from the Science Curriculum, 2015)

After replacing chemistry with physics in Johnstone's (2006) conceptual triangle, we can use the latter to explain why studying physics can place a high cognitive load on WMC and VSA and the adverse effects this can have on learning. By way of an example, we shall focus on electrical circuit theory as this represents a core topic in the physics curriculum (DfE, 2015).

To begin with, at the macro level, we need to understand that the voltage from the battery provides the push (or electromotive force) that drives the current through the circuit in a particular direction. In addition, we need to be cognisant of the fact that electrical resistance opposes the flow of the current through the circuit and must be overcome (DfE, 2015).

At the representational level, we need to know Ohm's Law, which states that voltage and current are proportional for a given value of resistance. This relationship can be expressed mathematically as $V = IR$ where V represents voltage, I represents current, and R represents electrical resistance (DfE, 2015). In addition, we need to have a good understanding of Kirchhoff's Laws; one of these states that the total current in the circuit is constant for a given voltage and resistance (DfE, 2015).

At the sub micro level, we must mentally visualize current as a collection of individual particles (called electrons); these electrons possess negative charge and reside inside the metal wires and electrical components (DfE, 2015). When we apply a voltage, these electrons flow or move in one direction; In doing so, they transfer electrical energy to other components in the circuit. In turn, these components transform electrical energy into other useful forms; for example, a loudspeaker will transform electrical energy into sound energy. In addition, we need to understand that these electrons never get used up in the process (DfE, 2015).

This example shows that in order to make sense of electrical circuit theory, we need to engage with all three dimensions (or corners) of the conceptual triangle and this can place a heavy cognitive load on WMC and VSA. If the learner's cognitive processing capacity cannot cope with the cognitive load, then '…the learner has insufficient capacity to handle all the ideas together, leading to an information overload. This tends to make understanding very difficult.' (Al-Ahmadi 2008:72). The next section considers how counter-intuitive ideas and concepts can place further cognitive load on WMC and VSA.

6.3.1.1.1 Understanding Counter-intuitive Concepts in Physics

Why does an apple always 'fall down' from an apple tree? Why does it not 'move upwards' or just hover in the air? According to the laws of physics, the apple does not 'fall down' at all. Instead, both the apple and the Earth move toward each other. However, given the enormous mass of the Earth compared to the mass of the apple, we do not notice the Earth moving toward the apple; instead, we observe the apple rushing toward the Earth. The idea that both the apple and the Earth move toward each other is counter-intuitive because it appears to disagree with our everyday experiences of how physical objects behave in the real world (Kumar et al., 2013; Reif, 2008; Reid, 1994).

In another example, when we place a book on a table, what prevents it from falling? Interestingly, Redish (1994) asked this question to teenage students and reported that, '...a significant fraction of…students do not believe that a table exerts a force on a book it is supporting. Why doesn't the book fall through? The table is '"just in the way" '(Redish, 1994:800). However, Newton's Third Law states that the weight of the book is counteracted by the table which exerts an equal force in the opposite direction. In order to make sense of what is happening in these examples, we often need to rethink our ideas, particularly at the macro level about what we believe is happening; this can be mentally taxing and require a good deal of cognitive processing capacity. Consequently, individuals who possess a large WMC and good VSA may have a learning edge when it comes to making sense of counter-intuitive ideas and concepts embedded in the physics curriculum

(Kumar et al., 2013; Taylor, 2013; Johnstone, 2006). The next section considers how the language of mathematics can impose its own cognitive load on WMC and VSA, especially at the representational level in Johnstone's (2006) conceptual triangle.

6.3.1.2 Mathematics in Learning Physics

Few would argue that physics relies heavily on the language of mathematics. Indeed, many academics contend that '...physics cannot be learned without a mathematics background' (Ornek et al, 2008:33). Expanding on this further Redish (1994) writes how: -

> 'Physics as a discipline requires learners to employ a variety of methods of understanding and to translate from one to the other...tables of numbers, graphs, equations, diagrams...Physics requires the ability to use algebra and geometry and to go from the specific to the general and back' (Redish, 1994:801).

Abstract ideas and concepts in physics are frequently expressed in the form of equations or formulae (Şahin and Yağbasan, 2012; Williams et al., 2003; Byrne et al., 1994). This means that at the representational level (in the conceptual triangle shown above), these formulae can add to the cognitive load on WMC and VSA. The problem below illustrates this point: -

> 'A force of 15 N acts on an object of mass 2 Kg. Calculate the acceleration of the object.' [3 marks]

(Adapted from the AQA Additional Science Examination, 2015)

This problem reflects the expectation of the physics curriculum that students should be able to '...apply Newton's Second Law in calculations relating forces, masses and accelerations' (DfE, 2015:25).

To solve the problem, we need to use the following formula: -

- F= m x a; where "F" represents the force in Newtons (N), "m" represents the mass of the object in Kg and "a" represents the acceleration of the object in m/s^2.

We then apply the rules of algebra to rearrange the equation as follows a = F ÷ m. Substituting the values into the equation gives the solution to the problem, $a = 15 \div 2 = 7.5\ m/s^2$. This relatively simple task required three cognitive steps. The first step involved identifying the correct formulae. The second step involved rearranging the formula using algebraic manipulation. The third step involved 'plugging-in' the numbers to solve the problem.

Of course, some students may avoid algebraic manipulation (step 2) altogether by electing to memorize all three versions of Newton's Second Law (F = m x a; a = F ÷ m and m = F ÷ a). However, employing either strategy imposes its own cognitive load. Moreover, the physics curriculum requires GCSE students to memorize about 20 formulae; memorizing these formulae and all their permutations will exact a heavy toll on WMC and VSA. In addition, graphs are also frequently used at the representational level to explain abstract ideas and concepts in physics, and these can place additional cognitive load on WMC and VSA as we shall find out in the next section.

6.3.1.2.1 Interpreting Graphs in Physics

Alongside formulae, graphs can also add to the cognitive load on WMC and VSA at the representational level in Johnston's model (2006; 1997; 1991). Indeed, in a wide-ranging investigation looking into why students find physics difficult, Ornek et al., (2008) reported: -

> '... that students find physics difficult because they have to contend with different representations such as experiments, formulas and calculations, graphs, and conceptual explanations at the same time. Moreover, they have to make transformations among them. For example, students need to be able to transfer from graphical representations to mathematical representations' (Ornek et al., 2008:30).

By way of illustration, consider the phenomenon of skydiving which features in the physics curriculum in the topic entitled Forces (DfE, 2015). The skydiving phenomenon addresses the following learning aim in the physics curriculum: -

> '…describe...the forces acting on an isolated...object or system; describe, using... examples where... forces lead to a resultant force on an object and the special case of balanced forces when the resultant force is zero (qualitative only)' (DfE, 2015:35).

Figure 10 describes what happens to the velocity of the skydiver as the individual falls toward the Earth in graphical form.

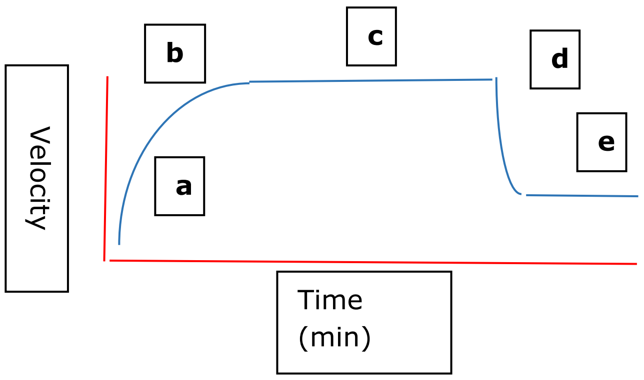


Figure 10: Skydiving

- **a.** The gravitational force (or weight) accelerates the skydiver toward the ground after exiting the airplane.
- **b.** As the skydiver falls, the resistive force acting in the opposite direction to the weight begins to build and decelerates the skydiver.
- **c.** The resistive force eventually matches the weight; the skydiver now falls toward the ground at a terminal velocity.
- **d.** The skydiver then deploys the parachute; this increases the resistive force and decreases the downward velocity of the sky diver.
- **e.** Eventually a new equilibrium between the skydiver's weight and the resistive force is established; the skydiver now falls at a much lower constant velocity.

The graph above is an abstract representation of a real-life phenomenon. Given that it is rich in both description and explanation, making sense of it can impose a heavy mental load on the WMC and VSA of the individual (Johnstone, 2006; Johnstone and El-Banna, 1986).

As discussed in the previous chapter, several studies report that individuals with strong visual spatial processing abilities generally do better when it comes to interpreting abstract ideas and concepts presented in graphical form (Bluchel et al., 2013; Martin-Gutierrez et al., 2013; Wai et al., 2009). However, not everyone possesses good VSA and several studies report that many students struggle when it comes to making sense of graphical representations (Al-Ahmadi, 2008; Redish, 1994). Given that the latter pervade a good portion of the physics curriculum this can be problematic as noted by Redish, (1994): -

> '"…I will never forget one day a few years ago when a student in my ... introductory physics class came in to ask about some motion problems. I said, "All right, let's get down to absolute basics. Let's draw a graph." The student's face fell, and I realized suddenly that a graph was not going to help him at all..."', (Redish,1994:802).

Redish (1994) is not alone in expressing this view; Al-Ahmadi (2008) observed how some Physics students experienced '…difficulties in connecting graphs to physical concepts…and…to the real world…' (Al-Ahmadi, 2008:79). In addition, the aforesaid researcher noted how some students found it especially difficult to interpret graphs comprising curves and straight lines (as in the case of the graph above).

Expanding further, Al-Ahmadi (2008) reported that a significant number of '... students find it more difficult to interpret curved graphs than straight-line graphs...and... have difficulty in drawing a velocity-time graph that is qualitatively correct for the motion of an object...' (Al-Ahmadi, 2008:79). Importantly, Al-Ahmadi (2008) argued that a good proportion of '…these difficulties can be ascribed to working memory overload' (Al-Ahmadi, 2008:79). Thus, mathematical language (expressed in the form of graphs and formulae etcetera) can place a heavy cognitive load on WMC and VSA at the representational level in Johnstone's (2006) conceptual triangle. This can make learning more difficult and challenging and increase the risk of cognitive overload, especially for students with a more limited WMC and VSA. As discussed in the next section, the adverse effects on thinking clearly and rationally when our WMC and VSA is taxed to its limits are perhaps even more evident when it comes to solving problems in physics.

6.3.1.3 Problem Solving in Physics

In physics tests and examinations, students are frequently required to solve problems, and this can place a high cognitive load on WMC and VSA. This is because problem solving generally involves engaging with all three corners of Johnstone's (2006) conceptual triangle at the same time. This means that in: -

> '...the study of physics…as a student is attempting to solve a problem, the student must first visualize the problem, secondly think of the physical principle that can be applied to this problem and then begin

to start applying the mathematical principle that pertains to this certain situation' (Hinojosa, 2015:15).

In a ground-breaking study, Johnstone and El-Banna (1989) investigated the relationship between cognitive load and solving problems in secondary school chemistry. They presented their core findings in the form of three graphs; these have been reproduced and are shown in Figure 11 below.

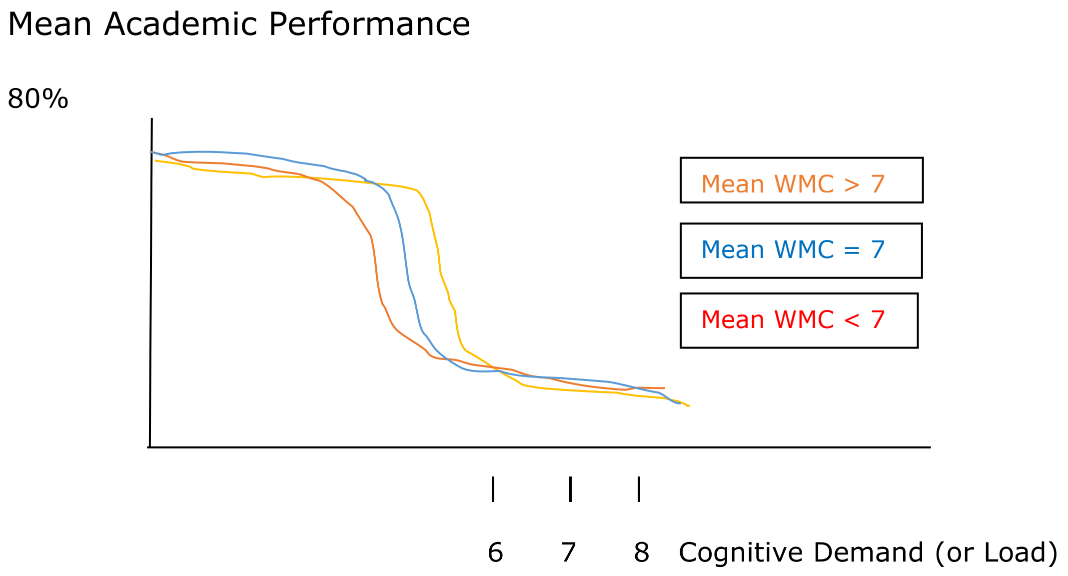


Figure 11: Academic Performance and Cognitive Load
(Adapted from Johnstone and El-Banna, 1989)

In Figure 11, academic performance represents the number of problems solved correctly and Cognitive Demand (or Load) signifies the mental effort needed to solve the problem. Johnstone and El-Banna, (1989) explain this in the following way: -

> 'By demand we mean the maximum number of thought steps and processes which had to be activated by the least able, but ultimately successful candidate in the light of what had been taught' (Johnstone and El-Banna, 1989:160).

The graphs show a shallow and broadly linear decline in academic performance as the problem becomes more complex and cognitive demand increases. When the mental load imposed by the problem approaches (and then surpasses) the cognitive processing capacity of the individual, academic performance falls away sharply. These findings clearly suggest that WMC is finite and when it is exceeded, our ability to think rationally and clearly can become severely degraded (Buettner, 2013; Paas and Sweller, 2011; Onwumere, 2009). Expanding on this further, Jalani and Lai, (2015) write: -

> '…information processing beyond the working-memory limits will result in memory saturation; which means that the working-memory cannot provide sufficient memory space or cognitive resources to perform cognitive activities such as learning' (Jalani and Lai, 2015:872).

Interestingly, these graphs also reveal that individuals with a bigger cognitive processing capacity can sustain academic performance for longer compared to those with a smaller cognitive processing capacity (Johnstone, 2006, 1991). Generalizing these findings beyond chemistry, Johnstone (2006) contends that although '…the emphasis here is on chemistry, the research applies to all science subjects…' (Johnstone, 2006:49). This contention seems to be borne out by findings from other studies (Ashcroft and Moore, 2009; Onwumere, 2009; Al-Enezi, 2008). For example, Danili and Reid (2004) investigated the relationship between cognitive demand and problem-solving ability in chemistry of students aged 15 to 16. They defined cognitive demand in terms of the minimum number of steps needed to solve a problem correctly. They found that 'When a test question makes a demand…greater than a pupil's working memory capacity, performance drops markedly' (Danili and Reid, 2004:219).

In another example, Onwumere (2009) investigated the relationship between AA in mathematics and WMC and VSA of students aged 15 to 16. As part of the overall conclusion, Onwumere (2009) reported that, '…in mathematics, the learner's working memory is easily overloaded in a learning situation because the content of the working memory is…limited in capacity…' (Onwumere, 2009:51). Collectively, these studies suggest that as cognitive load increases it becomes more difficult to think clearly and effectively. Moreover, if the cognitive load exceeds our cognitive processing capacity even by a small margin, our ability to process or make sense of information falls sharply. The findings from these studies broadly support the predictions made by CLT (Buettner, 2013; Paas and Sweller, 2008; Gathercole and Alloway, 2008). In the case of physics, effective learning or problem solving frequently involves engaging with all three dimensions of Johnstone's (2006) conceptual triangle at the same time; this can overload WMC and VSA and significantly reduce learning and understanding. Moreover, an individual with a more limited WMC and VSA is especially susceptible to cognitive overload (Taylor, 2013). From the standpoint of CLT, very little can be done to reduce the Intrinsic Cognitive Load (ICL) on the aforesaid variables as noted by Taylor (2013): -

> '…the inherent complexity of the information being received creates an intrinsic cognitive load that cannot be reduced without impacting the understanding of the learner' (Taylor, 2013:63).

However, it might be possible to cut down Extraneous Cognitive Load (ECL); this possibility is discussed in the next section.

6.3.2 Extraneous Cognitive Load (ECL)

From the standpoint of CLT, processing information that makes little impact on learning and understanding is represented by ECL (Jalani and Lai, 2015; Debue and Leemput, 2014; Gathercole et al., 2004). ECL is problematic because it uses up valuable WMC and VSA needlessly; In doing so, it effectively reduces cognitive processing capacity (DeBue and Leemput, 2014; Demetriou et al., 2002; Sweller et al., 1998). A reduction in WMC and VSA can undermine our ability to process information effectively and efficiently (Ashcroft and Moore, 2009; Onwumere, 2009). Consequently, '...extraneous load has to be kept as low as possible...' (DeBue and Leemput, 2014:2). In the educational setting ECL can be introduced in a variety of ways; examples include ineffective teaching practices; inefficient methods for presenting information and learning tasks and poorly crafted test or examination questions (Skulmowski et al., 2017; Kwaja et al., 2014; Johnstone, 2006).

Moreover, the literature review suggests that science teachers are generally unaware of the damaging effects ECL can have on the learning or sense making process (Kumar et al., 2013; Reif, 2008; Johnstone, 2006). For example, in relation to chemistry, Johnstone (2006) argues that '...the fault lies with the teacher for creating situations of gross overload…' (Johnstone, 2006:58). The researcher cites experiments in chemistry as particularly good examples of ECL: -

> 'Written and verbal instructions, unfamiliar equipment and chemicals, observing and recording; all these together occupy Working Memory Space leaving no room for cognitive processing' (Johnstone, 2006:56).

Johnstone (2006) goes on to implore chemistry teachers to reflect on how '…to present material to avoid overload, to optimise processing and sense-making and to facilitate storage and recall' (Johnstone, 2006:57). The latter also contends that using '…diagrams, illustrations and physical models can help reduce cognitive load on WMC '(Johnstone, 2006:58). Moreover, this contention is rooted in CLT; for reasons that are not entirely clear, presenting information simultaneously in both visual spatial and audio verbal modes appear to place less cognitive load on WMC and VSA compared to presenting information in one mode only. Incorporating ideas from IPT, the WMM and CLT, Hindal et al (2009) tentatively propose the following reasons why the dual approach appears to reduce the overall cognitive load on WMC and VSA: -

> 'It has been shown that the working memory has two loops (one a visual–spatial sketchpad, the other an auditory/verbal loop) ... In an interesting experiment...it was found that presenting questions in visual form helped some students, the symbolic form helped others...while presenting in both forms gave the best overall results.... This could be explained by the use of both working memory loops or it could be explained by the idea that storing information in two forms gives the greatest advantage. It could also simply be that, if information is stored in multiple ways, there are more links and, therefore, a better chance of reaching a desired piece of information' (Hindal et al., 2009:196-197).

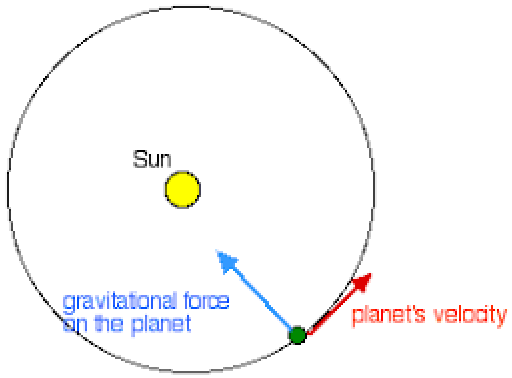
For example, consider the cognitive load on WMC and VSA when processing information presented in the self-created paragraph below: -

> The Earth orbits the Sun at a mean distance of 150.41 Km in an approximately circular orbit. A complete revolution of the Earth around the Sun takes 365.25 days. The Sun is by far the most massive body in the solar system. In fact, the Sun constitutes better than 99.8% of the mass of the entire solar system including all the planets, moons, asteroids, comets and other celestial bodies that make up the solar system. In addition, given its huge mass, the Sun exerts an incredibly strong gravitational force of attraction or pull on the Earth. The gravitational pull keeps the Earth in a relatively tight orbit around its parent star. Were it not for the tangential velocity of the Earth relative to the Sun, the Earth would accelerate toward the Sun and eventually fall into it. This makes the Sun by far the most important celestial body in our solar system.

The paragraph relates to the physics curriculum as follows: -

> 'Space physics; Solar system, stability of orbital motions...Explain for circular orbits how the force of gravity can lead to changing velocity of a planet but unchanged speed, and explain how, for a stable orbit, the radius must change if this speed changes...' (DfE, 2015:44-45).

If we added a few more paragraphs like the one above (related to this topic) and presented it to our students, we perhaps should not be surprised to find that we had put a considerable strain on their cognitive processing capacity, perhaps even to the point of overloading it. Figure 12 shows how we can present the same information using both the audio verbal and the visual spatial processing loops comprising cognitive processing capacity.



mean distance between Earth and Sun is about 150 Km

Sun accounts for 98.8% mass of the entire solar system

Earth takes approx 365 days to orbit the Sun

Figure 12: Presenting Information via Multiple Modalities (Adapted from Batesville Community Schools, 2019)

Instead of relying almost exclusively on the audio verbal loop for processing information (as in the first case), we can now spread the cognitive load more evenly across both loops by activating the visual spatial processing loop at the same time. This action can reduce the overall cognitive load and lead to more effective and efficient information processing (Hindal et al., 2009; Kirshner et al., 2006).

There is strong evidence in the published literature suggesting that adopting the second approach can reduce the overall cognitive load on WMC and VSA (Lusk et al., 2008; Clark and Lyons, 2004; Mayer, 1996). For example, Danili and Reid (2004a) redesigned a major portion of the learning scheme in chemistry at a secondary school. In addition to removing elements in the learning scheme they felt generated ECL, they encouraged the chemistry teachers to make greater use of diagrams, schematics, sketches, 3-D models (etcetera) when teaching the redesigned learning scheme. They reported a noticeable overall improvement in AA and argued that this was due to the aforesaid changes and independent of teacher effects (Danili and Reid, 2004a). However, it is not clear which of the two aforesaid changes had the biggest impact on improving AA in mathematics. In addition, Danili and Reid (2004a) are rather vague in explaining how they isolated and accounted for teacher effects and other confounding variables. It is also not entirely clear how they identified ECL in the scheme of learning.

In another example, Sweller (1994) found that students who were taught mathematics using mixed audio verbal and visual spatial methods obtained higher average scores in tests compared to those who had been taught almost entirely via audio verbal mode. Sweller (1994) attributed these improvements to a fall in the overall cognitive load on WMC and VSA. Sweller (1994) argued that the drop in cognitive load facilitated more efficient and effective information processing - ultimately leading to deeper learning and understanding (Sweller, 1994). The adage “a picture is worth a thousand words” neatly summarizes the benefits that can be derived from making better use of VSA.

Given that ICL can be very high in STEM subjects (discussed earlier) it is important to reduce ECL as much as possible in order not to over tax WMC and VSA (Ornek et al., 2008; Shekoyan and Etkina, 2007; Kirshner et al., 2006). This is because '…people only have a certain capacity of verbal memory such as words or sounds as well as limited amount of spatial ability...', (Hinojosa, 2015:14) with which to process or make sense of information. Consequently: -

> 'When the intrinsic cognitive load is high (learning content is difficult) and the extraneous cognitive load is...high, the amount of cognitive load will overcome the mental resources and the learning process will probably fail' (Jalani and Lai, 2015:874).

This dimension of my study adds fuel to the ongoing debate in the field of physics education of how best to teach and assess learning and understanding. From the perspective of CLT, overtaxing WMC and VSA should be avoided since this can adversely affect learning and understanding; indeed, Kirshner et al., (2006) make a much wider point by arguing that 'Any instructional theory which ignores the limits of working memory ...is unlikely to be effective' (Kirshner et al., 2006:77). Consequently, it is argued that curriculum planners and physics teachers need to take greater account of the finite nature of WMC and VSA when planning the physics curriculum and deciding on a suitable teaching approach. In addition, examining bodies (such as the AQA and Edexcel) need to reflect more carefully on the limited nature of cognitive processing capacity when crafting summative assessments in physics. The next section discusses the third important cognitive load on WMC and VSA that can arise from studying physics.

6.3.3 Germane Cognitive Load and Creating Schemata

Germane Cognitive Load (GCL) represents another important type of cognitive load that can be placed on WMC and VSA as part of the learning or sense making process (Chandler and Sweller, 1992). GCL is desirable because it facilitates nourishing and productive thinking and plays a key role in the acquisition of new skills, knowledge and understanding (Paas et al., 2008; Kirshner et al, 2006). Thus, '…germane cognitive load…helps in the learning process.' (Jalani and Lai, 2015:874). GCL load plays a central role in helping us to create schemata or mental learning frames. Debue and Leemput, (2014) explain this as follows, 'Germane load…refers to the mental resources devoted to acquiring and automating schemata…' (Debue and Leemput, 2014:2). These schemata or mental models represent the pattern of thinking which an individual employs on a particular learning or sense making journey. Redish (1994) defines the latter as follows 'I use the term mental model for the collection of mental patterns people build to organize their experiences related to a particular topic' (Redish, 1994:797). From the perspective of CLT, as we progress through life, we develop multiple schemas, some simple, others more complex (Paas et al., 2004). Clarke et al., (2005) explain this as follows: -

> 'We hold schemas for people, household objects and 'script' schemas for routines and events such as our morning routine, as well schemas for particular 'roles' that we find people enacting, which tell us what kind of behavior to expect of them' (Clarke et al., 2004:11).

Consequently, when we come across something outside our current bank of knowledge, skills and experience, we begin constructing a schema (Jalani and Lai, 2015). For example, when we encounter something new or unfamiliar in physics, some of us are initially unsure what to do. That is because we do not have a schema to inform and guide our thinking. To find a solution to the problem, some of us will try a range of different approaches; consequently, GCL on WMC and VSA will be relatively high. For example, consider the following problem related to the topic of momentum in the physics curriculum (DfE, 2015). Let us imagine that this problem is unfamiliar to us: -

> 'A trolley of mass 80 Kg, which is initially at rest, is struck by a bullet of mass 20 grams travelling at a speed of 400 m/s. The bullet becomes lodged in the trolley on impact. What is the velocity of the trolley-bullet system immediately after this event'? Ignore frictional effects [4 marks)].

(Adapted from the AQA GCSE Additional Science Examination, 2015)

We can begin developing a schema to address the problem; one possible approach is described below: -

Step 1: We start by reflecting on the concept of momentum which represents a physical property of all objects that have mass and are in motion. Empirically, momentum is given as a product of mass and velocity (momentum = mass x velocity). We also need to be familiar with the Law of Conservation of Momentum, which states that the total momentum remains unchanged during any physical interaction.

Step 2a: We can now apply these notions to the problem at hand using the language of mathematics

Initial Momentum of the trolley = mass of the trolley x velocity = 80 x 0 = O kg m/s

Step 2b: Initial Momentum of the bullet = mass of the bullet x velocity = 0.02 x 400 = 8 kg m/s

Step 3: Momentum of the trolley after being struck by the bullet = (mass of the trolley plus mass of the bullet) x velocity = (80 + 0.02) x velocity (representing the unknown value)

Step 4 Using the Law of Conservation of Momentum

0 + 80.02 x velocity = 8 + 0 therefore velocity of the trolley (plus bullet) = 8 ÷ 80.02

Answer = 0.1 m/s (correct to 1 decimal place)

Once created, we can use this schema whenever we come across a broadly similar problem. Moreover, since we now largely know what to do, there is no need to spend a lot of mental effort thinking about what we are doing. Taylor, (2013) explains this as follows, '…cognitive schemas… can be…retrieved and processed quickly without putting an excessive burden on working memory (Taylor 2013:62). Consequently, we can solve problems of a similar nature without taxing our WMC and VSA too much; this is because we have a ready-made schema stored in our Long-Term Memory (LTM) which we can use to guide our ideas and thoughts (Buettner, 2013; Taylor, 2013).

6.4 Strengths and Weaknesses of Cognitive Load Theory (CLT)

Since its inception about 20 years ago, CLT has become firmly established as a leading theory in the field of educational psychology. CLT generally shares many of the strengths associated with IPT and the WMM; these include a robust and well-developed theory and predictions that can be tested. Moreover, many studies have broadly confirmed the outcomes predicted by the theory (Hinojosa, 2015; Jalani and Lai, 2015; Kirshner et al., 2006). A major weakness of CLT relates to the difficulties involved in differentiating between the three major types of cognitive load on WMC and VSA (Taylor, 2013; Webb et al., 2007; Wills, 2007). Instead of having distinct identities and well-defined boundaries as claimed by CLT, critics argue that ICL, ECL and GCL overlap extensively and this makes it difficult to distinguish between them (Taylor, 2013; Webb et al., 2007; Wills, 2007). In their view, this makes it difficult to agree on what counts as ICL, ECL and GCL (Taylor, 2013; Webb et al., 2007; Wills, 2007). However, advocates of CLT largely dismiss these claims; they point to findings from numerous studies that broadly confirm the predictions made by this theory (Hinojosa, 2015; Jalani and Lai, 2015; Kirshner et al., 2006).

6.5 Conclusion

My study found a positive linear correlation between GCSE grades in physics and WMC and VSA respectively. From the standpoint of IPT and the WMM, these outcomes can be explained in terms of cognitive processing capacity (comprising WMC and VSA). Specifically, they contend that individuals with a relatively large cognitive processing capacity can retain and process more information. This can be advantageous when studying a complex and multifaceted subject such as physics. For example, possessing a large cognitive processing capacity can help us to mentally visualize abstract ideas and concepts more vividly; perceive patterns in data more clearly; interpret graphs more accurately and make better sense of schematics, diagrams and formulae.

Employing the theoretical perspectives afforded by CLT, the chapter also discussed the three key types of cognitive load that can be placed on WMC and VSA when learning physics; these include ICL, ECL and GCL. The first relates to the intrinsic complexity of the subject we are trying to learn; consequently, we can do very little to reduce ICL. The second relates to the processing of information that contributes very little to learning; thus, ECL represents mental effort that is largely wasted. We can potentially reduce ECL given that much of it arises from inefficient teaching methods and practices. GCL represents the third major cognitive load on WMC and VSA;

the latter is considered important and necessary because it can benefit learning and reduce the overall cognitive load in the long term.

Crucially, if the cognitive load imposed by either (or all) of these variables (ICL, ECL and GCL) exceeds the WMC and the VSA of the individual, learning and understanding can decline sharply; this is because we can no longer process or make sense of information efficiently or effectively. However, those individuals with a bigger WMC and VSA are less likely to experience cognitive overload, and this can give these individuals a learning edge or advantage in physics. The next chapter spotlights the outcomes yielded from investigating the relationship between GCSE grades in physics and Attitudes towards Physics (AP).

Chapter 7 Analysis of Attitudes towards Physics (Part I)

7.1.1 Introduction

As part of my overall research, I investigated the nature and strength of the correlation between GCSE grades in physics and AP. I also explored the key factors involved in the development of AP. This chapter reveals the findings pertaining to the aforesaid aims; it is divided into two parts. Part I relates to the first aim and reveals the nature and strength of the correlation between GCSE grades in physics and AP. These outcomes were secured after analysing the quantitative data on the participants AP via statistical analysis. Part II relates to the second aim and reveals the key factors contributing toward the development of AP. These factors were identified after analysing the quantitative and qualitative data on the participants AP via statistical and thematic analysis respectively. Both parts include a detailed discussion on how the respective findings develop knowledge and understanding in the field of physics education.

The chapter then breaks down into four subsections. The first subsection focuses on the PMCC (or r_s); this was used to test the strength of the linear correlation between the aforesaid variables. The second subsection reveals the Multiple Regression Equation (MRE) that was used to model the collective influence of WMC, VSA and AP on GCSE grades in physics. The third subsection shows the estimated Confidence Interval (CI) for the mean AP value of the population from which the two samples were drawn. The population refers to all KS4 students attending state funded secondary schools in Bradford (Field, 2014, Nolan and Heinzen, 2011). Table 12 summarizes the overall statistical approach that I used in this part of the chapter.

Table 12: Statistical Analysis Overview pertaining to AP

Statistical Analysis	Statistical Tool
Compared the mean and SD of the participants' AP scores from each school. Purpose: To understand the homogeneity of the items within and between the two datasets.	Applied descriptive statistical methods and Cohen's d
Established whether the participants' AP from each school was broadly favourable or unfavourable. Purpose: To determine if the aforesaid outcomes resonate with those reported in the published literature. In addition, to reflect on the wider implications of this finding on physics education.	Applied descriptive statistical methods
Tested the following hypotheses: H_o (null hypothesis): There is no correlation between GCSE grades in physics and AP. H_1 (alternative hypothesis): There is a correlation between GCSE grades in physics and AP. Purpose: To determine if there were sufficient grounds to reject H_o in favour of H_1 and to contextualize the outcomes within the broader literature.	Applied PMCC (or r_s) for $p < 0.05$ level of significance
Established the Multiple Regression Equation (MRE) for the dependent variable (GCSE grades in physics) and the independent variables (AP, WMC and VSA). Purpose: To model the relationship between the dependent variable and the independent variables.	Used Multiple Regression Analysis (MRA) to establish the Multiple Regression Equation (MRE)
Calculated the CI pertaining to mean AP population parameter. Purpose: To estimate the value of the mean AP population parameter.	Applied standard statistical methods for calculating CI

7.1.2 Analysis of Mean and SD of AP scores

Table 13 summarizes the mean and SD of the participants AP scores from school-A, and from school-B respectively.

Table 13: Attitudes towards Physics (AP) Scores

Institute	Mean AP Score	Standard Deviation of AP Score
School-A	159.38 (2 DP)	19.52 (2 DP)
School-B	172.00 (2 DP)	23.98 (2 DP)

Table 13 shows that participants from school-B had a higher mean AP score compared to those from school-A. This shows that on average, participants from school-B had relatively more positive AP compared to those from school-A. The AP questionnaire gauged the relative strength of the response to a statement or question using an interval scale (shown in Appendix 3). The more strongly a participant agreed with a positively worded statement or question, the higher the score achieved. For a negatively worded statement or question, the interval scale was reversed; thus, a high mean score reflects a more positive AP and vice versa. Cohen's d value of 0.58 (2 DP) suggests that the difference between the average scores is only mildly significant (Field, 2013; Nolan and Heinzen, 2011). This can be interpreted as showing that there is a quite a high probability that the difference between the values is due to chance. In addition, the participants' AP scores from school-A (SD=19.52) were clustered more closely compared to those from school–B (SD=23.98).

7.1.3 GCSE Grades in Physics versus AP scores

The Product Moment Correlation Coefficient (PMCC or r_s) was used to investigate the strength of the linear correlation between GCSE grades in physics and the AP scores of the participants sampled from each school.

Table 14: GCSE Grades in Physics versus AP scores

Institute	GCSE grades in physics versus Attitudes towards Physics (AP) scores
School-A	r_s = 0.28 (2 DP)
School-B	r_s = 0.30 (2 DP)

The r_s values shown in Table 14 reveal a weak to moderate positive correlation between GCSE grades in physics and AP scores of the participants from each school (Nolan and Heinzen, 2011). A r_s value between 0.20 and 0.39 is generally deemed to represent a weak to moderate positive correlation between two variables (Mujtaba and Reiss, 2014; Nikolic et al., 2012; Evans, 1996). The r_s values show that the participants with a more favourable AP (reflected in a higher AP score) tended to attain better overall grades in GCSE physics compared to those with a less favourable AP (reflected in a lower AP score).

7.1.4 Testing the Null Hypotheses

The aforesaid r_s values made it possible to reject the null hypothesis in favour of the alternative hypothesis, namely that there is a positive linear correlation between GCSE grades in physics and AP scores. In relation to school-A (n=45), we can reject Ho in favour of H_1 if $r_s > 0.27$ at the 0.05 level of significance for a sample between 40 and 49 in a one tailed test (Wilcox, 2017; Nachmias and Guerrero, 2014). In relation to school-B (n=55), we can reject Ho in favour of H_1 if $r_s > 0.25$ at the 0.05 level of significance for a sample between 50 and 59 in a one tailed test (Wilcox, 2017; Nachmias and Guerrero, 2014). The significance of these findings is discussed in the next section.

7.1.5 Confidence Interval (CI) for the mean AP scores

This section reveals the CI for the estimated value of the population parameter corresponding to the mean AP score for the participants from each school. The latter are summarized below in Table 15.

Table 15: Confidence Interval for mean AP scores

Confidence Interval (CI)	School-A	School-B
CI for the mean AP scores (rounded to the nearest whole number)	CI = (154,165) CI size = 165 – 154 = 9 Margin of Error = +/- 6	CI = (166,178) CI size = 178 – 166 = 12 Margin of Error = +/- 6

The CI shown in Table 15 (for each school) represents the range of values that may include the unknown population parameter related to the mean AP score at the 95% confidence level; thus, there is a very good chance that the range contains the unknown population parameter. Table 15 shows that the CI from school-A just fails to overlap with the CI from school-B; this suggests that the difference between the two mean AP scores is only mildly significant (Field, 2014). This view is further reinforced by Cohen's d value of 0.58 which also points to a mildly significant difference between the mean AP scores of the participants from each school (Nolan and Heinzen, 2011). In this situation, the CI pertaining to school-A is deemed more likely to contain the mean AP score of the wider population. This is because the sample with the smaller CI size is generally regarded as providing a better estimate of the unknown population mean (Field, 2014; Nolan and Heinzen, 2011). Thus, the CI of magnitude 9 (from school-A) is preferred over the CI of magnitude 12 (from school-B).

7.1.6 Multiple Regression Analysis (MRA)

IPT and AT predict a positive linear correlation between GCSE grades in physics and the cognitive-affective variables (WMC, VSA and AP) respectively. However, precisely how much and in what proportion to other factors is largely left unanswered by both theories. I used Multiple Regression Analysis (MRA) to bridge this perceived gap in the literature. Specifically, MRA was used to establish the precise strength and nature of the correlation between the dependent variable (GCSE grades in physics) and the independent variables (WMC, VSA and AP). MRA was also used to understand how changing the independent variable (or variables) affected the dependent variable; Table 16 shows the key outcomes from MRA.

Table 16: Summary Table of Multiple Regression Analysis (MRA)

Test Statistic	Mathematical or Symbolic Form	School-A (3 sig fig)	School-B (3 sig fig)
Coefficient of Multiple Regression	R^2	0.213	0.197
Analysis of Variance (ANOVA)	Significance-F	5.92 or $p<0.00543$	12.65 $P<0.000801$
Multiple Regression Equation (MRE) for school-A	$Y_{schA} = m_{WMC}x_{WMC} + m_{AP}x_{AP} + C$ (no data on VSA, therefore this variable not included in MRE)	$Y_{schA} = 0.553X_{WMC} + 0.0204\ X_{AP} + 3.20$	
Multiple Regression Equation (MRE) for school-B	$Y_{schB} = m_{WMC}x_{WMC} + m_{VSA}x_{VSA} + m_{AP}x_{AP} + C$		$Y_{schB} = 0.0113_{AP} + 0.0903_{VSA} + 0.187_{WMC} + 0.612$
Coefficient of Multiple Correlation	R	0.469	0.439
y-values corresponding to WMC, AP and VSA equal zero	C	3.20	0.612
Observations	Data points	45	55

Key

- R^2 represents the coefficient of multiple regressions.
- Y_{schA} represents the mean predicted GCSE grades in physics for the participants from school-A.
- Y_{schB} represents the mean predicted GCSE grades in physics for the participants from school-B.
- m_{WMC} represents the regression coefficient of the independent variable WMC.

- m_{VSA} represents the regression coefficient of the independent variable VSA.
- m_{AP} represents the regression coefficient of the independent variable AP.
- R represents the coefficient of multiple correlation.
- 'C' gives the y-value when WMC, VSA and AP are all to equal zero.
- x_{WMC}, x_{VSA} and x_{AP} represent the numerical data-values that can be taken by each independent variable.

The parameter R^2 reflects how well the observed data fit onto the regression line; the closer R^2 is to 100%, the better the fit (Field, 2014; Pallant, 2013; Nolan and Heinzen, 2011). The R^2_{schA} value for school-A reveals that 21.3% of the variability in the dependent variable (GCSE grades in physics) can be explained by the two independent variables (WMC and AP). This represents a mild level of agreement between the dependent variable and the two independent variables. I could not include VSA in the MRA because I did not have the data pertaining to this independent variable.

The R^2_{scB} value (for school-B) shows that 19.7% of the variability in the dependent variable (GCSE grades in physics) can be explained by the three independent variables (WMC, VSA and AP). This represents a mild level of agreement between the dependent variable and the independent variables; it is also broadly consistent with the R^2_{schA} value (21.3%) obtained for school-A. Significance-F represents the significance level (or p-level) for the test; in my study the p-level was set at $p<0.05$. The significance level was used to test the null hypothesis (H_o) and alternative hypothesis (H_1) given below.

H_o: There is no linear relationship between the dependent variable and the independent variables.

H_1: There is a linear relationship between the dependent variable and the independent variables.

The F-statistic for school-A is quite large (5.92) and the p-value ($p<0.00543$) is well below that set for the test ($p<0.05$). Therefore, we can confidently reject the null hypothesis (H_o) in favour of the alternative hypothesis (H_1). The confidence in rejecting the null hypothesis (H_o) is further reinforced by the multiple regression coefficient (R) value of 0.469; the latter points to a moderate linear relationship between the dependent variable and all the independent variables combined (Field, 2014; Hinton et al., 2014; Nolan and Heinzen, 2011). The F-statistic for school-B is quite large (12.65) and the overall p-value ($p<0.000801$) is well below that set for the test ($p<0.05$). Therefore, as in the case of school-A, we can confidently reject the null hypothesis (H_o) in favour of the alternative hypothesis (H_1). The confidence in rejecting the null hypothesis (H_o) is further reinforced by the R_{schB} value (0.439); the latter points to a moderate linear relationship between the dependent variable and all the independent variables combined. In addition, the aforesaid value broadly resonates with the R_{schA} value (0.469) obtained for school-A; this further strengthens the case for rejecting H_o in favour of H_1 (Field, 2014; Nolan and Heinzen, 2011). The regression coefficient (m) which is commonly used to measure Effect Size (ES) gives the following values: m_{WMC}= 0.553_{schA} and 0.187_{schB}; m_{AP}= 0.020_{schA} and 0.011_{schB}; m_{VSA}= 0.100_{schB}. Given that ES reflects the relative impact of the independent variable on the dependent variable, these values show that GCSE grades in physics are more strongly influenced by the cognitive variables (WMC and VSA respectively) and less strongly influenced by the affective variable (AP) from a statistical standpoint (Field, 2014; Nolan and Heinzen, 2011).

The slope values shown in Table 16 suggest that improving the AP score by 50 units should lead to a whole grade improvement. This calculation is based on the Ofqual (2018) grading scale (see section 4.2). At this stage it is unclear if a positive shift of this magnitude in AP is possible. It appears unlikely given that AP would have to shift by at least 2 standard deviations. Similarly, improving VSA by 11 units or WMC by 2 to 5 units should also yield a whole grade improvement. Currently, it is unclear if cognitive or mental training can bring about this level of improvement in either WMC or VSA. It could potentially be achievable given that VSA or WMC would have to improve by less than 1 SD. However, even a small increase in any of the aforesaid variables could potentially improve overall GCSE scores. This might still be worthwhile, especially for learners on the cusp of achieving better grades; a future study could investigate these possibilities in greater depth. When we combine this outcome with the growing body of evidence suggesting that AP respond well to mental training, it leaves us with the interesting possibility of improving overall GCSE grades in physics by targeting AP; this possibility is discussed in greater depth in section 7.1.7. Given that none of the participants scored zero on any of the tests (including on the AP questionnaire), the ‘C’ values (3.2 and 0.61) provide little useful information and are largely notional.

The p-values for AP ($p<0.067$) and WMC ($p<0.227$) are higher than those set for the test ($p<0.05$); nevertheless, these independent variables have been included in the MRE for school-B (shown in Table 16). Their inclusion is based on the argument that if an independent variable is believed to influence the dependent variable either theoretically or because of findings from previous research, it should be included in the MRE regardless of the p-value (Field, 2014; Nolan and Heinzen, 2011). Summarizing, MRA was carried out to determine the combined influence of the independent variables on the dependent variable. MRA shows that the two individual level cognitive variables (WMC and VSA) exert a stronger influence on the overall GCSE grades in physics compared to the individual level affective variable (AP); the MREs reflect these strengths in mathematical form (Table 16).

The outcomes from MRA suggest the possibility of improving overall GCSE grades in physics by enhancing WMC, VSA and shifting AP in a more positive direction. Importantly, the published literature is replete with studies suggesting that the two individual level cognitive variables (WMC and VSA) can be improved through targeted training; this dimension of my research was discussed in Chapter 2, section 2.1.6.1. In addition, numerous studies have reported that attitudes can be shifted in a more positive direction given the right conditions; this dimension of my research is covered in Chapter 8, section 8.7. When viewed together, they strongly point to the possibility of improving overall GCSE grades in physics by targeting WMC, VSA and AP.

7.1.7 Cause and Effect

I expected to find a positive linear correlation between GCSE grades in physics and the two individual-level cognitive variables (WMC and VSA) respectively. This expectation, rooted in IPT was discussed at length in Chapter 5. Summarising, IPT asserts that an individual with a bigger WMC and well developed VSA can process more information compared to someone with a more limited WMC and less well developed VSA. Moreover, the individual with the more expansive cognitive processing capacity can potentially make sense of information at a much deeper level. It is generally assumed that higher grades reflect this deeper level of learning and understanding (see Chapter 2, section 2.1.8). Also, findings from several studies suggest that WMC and VSA influence AA in STEM subjects at the lower tier of secondary education (see Chapter 5).

I also expected to find a positive linear correlation between GCSE grades in physics and the individual-level affective variable AP. This expectation, grounded in AT is discussed at length in Chapter 8. For example, AT contends that AP can influence the extent to which an individual is willing to engage in learning physics. Thus, a determined and driven individual may invest more time and mental effort in learning physics and achieve a higher grade as a result (see Chapter 8).

In the event, I did find a statistically significant positive correlation between GCSE grades in physics and the cognitive-affective variables respectively (see Chapter 7, section 7.1.6). Using criteria summarised by Taris (2000) and updated by Taris and Kompier (2016), I argue that these correlations may point to a causal relationship between the aforesaid variables.

Taris and Kompier (2016) suggest that, at a bare minimum, we can potentially identify a causal relationship using the criteria below: -

Criterion 1: The two variables must vary or change together.
Criterion 2: The relationship between the two variables must be plausible and grounded in a sound theoretical framework.
Criterion 3: The cause must precede the effect.

Criterion 4: The relationship between the two variables must be non-spurious.

Criterion 5: There must be no intervening factor (or factors) that could potentially account for the correlation between the two variables under investigation.

(Adapted from Taris and Kompier, 2016)

Given that I found a statistically significant positive correlation between GCSE grades in physics and WMC, VSA and AP respectively, my research findings broadly meet the first criterion. I then used theories from the field of educational psychology to potentially explain the influence of the aforesaid variables on GCSE grades in physics; this broadly meets the second criterion. In relation to criterion 3, I argue that the relationship between the cognitive variables and GCSE grades in physics may be directly causal. Specifically, a change in WMC or VSA ('the cause'), may produce a change in the physics grade ('the effect'). However, the relationship between GCSE grades in physics and AP may be bidirectional (see Chapter 8). For example, an individual who is favourably disposed towards physics may engage more deeply with this subject and achieve a higher grade. The latter may help develop even more positive AP. Several studies have reported finding a bidirectional link between AA in science and AS at the lower tier of secondary education (see Chapter 8, section 8.3). Although these studies (in conjunction with my own findings) strengthen the possibility of a bidirectional link between AA in physics and AP, more research is needed in this area.

It is unclear if my research findings meet the remaining criteria. For example, with respect to criterion 4, it is possible that the positive correlation between WMC and GCSE grades in physics may have arisen purely by chance (Drost 2011). Even though this possibility is extremely low (given that I used a p-value <0.05), it cannot be ruled out (Field, 2014; Nolan and Heinzen, 2011). In relation to criterion 5, confounding variables may be responsible for producing the correlations identified by my research. Although the nature of these confounding variables (if they exist) is unclear and needs to be investigated further, there are possible candidates. For example, family cultural capital could potentially influence GCSE grades in physics by enabling parents to better help their children with learning physics. This help could include providing a supportive and stimulating learning environment and inculcating positive AP and learning in general. Summarising, although my research goes some way toward establishing a causal relationship between the aforesaid variables, further research is needed in this area.

7.1.8 Original Contribution

The PMCC (or r_s) values shown in Table 16 point to a weak to moderate positive correlation between GCSE grades in physics and AP (Mujtaba and Reiss, 2014; Nikolic et al., 2012; Evans, 1996). These findings broadly chime with those reported in other studies (discussed in Chapter 2). For example, several studies report a positive linear correlation (ranging from weak to strong) between AA in STEM subjects and attitudes towards STEM subjects (Belgecan, 2012; Cakici et al., 2011; Cheung, 2009; Osborne and Dillon, 2008).

With respect to this dimension of my research, I have made three important contributions in the field of secondary physics education. Firstly, in finding a positive linear correlation between GCSE grades in physics and AP, my study has strengthened the generalization alluded to in the wider literature, namely that AA in STEM subjects is influenced by attitudes towards these subjects. Secondly, by establishing the strength of the correlation (weak to moderate) between the aforesaid variables, my study has added another layer of knowledge and understanding in this field; previously, the strength of the correlation between the aforesaid variables was not known. Thirdly, my findings become more striking and useful when we consider the mounting evidence in the wider literature (discussed in Chapter 2) suggesting that attitudes can be shifted in a more positive direction given the right conditions (Metin and Camgoz, 2011; Erdermir, 2009; Festinger, 1957). When viewed in tandem with my findings, they strongly point to the possibility of improving overall grades in GCSE physics by shifting AP in a more positive direction. Moreover, as discussed earlier this possibility receives strong support from two important sources. Firstly, AT predicts a positive correlation between AA in physics and AP. Secondly, several studies have reported a robust positive correlation between AA in STEM subjects and Attitudes. A future study could investigate if shifting AP in a more positive direction yields an overall improvement in GCSE grades in physics.

7.1.9 Conclusion

As part of my overall aim, I investigated the relationship between GCSE grades in physics and AP. Part I revealed the findings from this dimension of my study, specifically this part:

- Identified a positive linear correlation between GCSE grades in physics and AP scores of the participants from each school.
- Rejected the null hypothesis (H_0) in favour of the alternative hypothesis (H_1) based on the strength of the correlation between GCSE grades in physics and the AP scores of the participants.
- Established the MRE for GCSE grades in physics and the AP scores of the participants.
- Calculated the estimated CIs at the 95% level of confidence of the unknown population parameter corresponding to mean AP.
- Discussed the possibility of raising overall GCSE physics by shifting AP in a more positive direction via targeted intervention.

In addition, MRA was used to establish the MRE between GCSE grades in physics and WMC, VSA and AP collectively. The implications arising from MRA were also discussed at some length.

7.2.1 Discussion of the Key Factors Influencing AP (Part II)

This represents part II of Chapter 7 and reveals the key factors that potentially influence the respondents AP. The chapter begins with a brief review of the overall approach used to gauge and potentially explain the participants AP. The quantitative data on attitudes (obtained from the questionnaires) was scrutinised via statistical analysis and the qualitative data on attitudes (garnered from two focus group interviews) was examined using thematic analysis. The full questionnaire can be found in Appendix 3 and the focus group interview schedule can be found in Appendix 4. The quantitative and qualitative data linked to AP are available on request.

7.2.2 Review of the Method used to Investigate AP

I explored the relationship between GCSE grades in physics and AP using a four-fold approach. Firstly, I used statistical analysis to test the relationship between the aforesaid variables predicted by AT. After finding a statistically significant positive correlation between the aforesaid variables (see Chapter 7, section 7.1.4), I used AT to potentially account for this correlation (see Chapter 8). This represents the deductive dimension of my research (in relation to attitudes). Secondly, I identified the key factors that influence AP. I did this by analysing the quantitative data (obtained from the questionnaires) using the analytical method suggested by Saris and Gallhofer (2014); see Chapter 3, section 3.2.5.1. Thirdly, I carried out a thematic analysis of the qualitative data from the two focus group interviews to better understand the influence of these key factors on the respondents' AP (see Chapter 7, section 7.2.2.1 to section 7.2.2.7 inclusively). The focus group interviews were also intended to provide a space for new and unexpected issues to arise. However, this aspect of my research was significantly curtailed because of the 20-minute time limit placed on each focus group interview by the two schools that took part in my research. Although the focus groups were not as effective as I had hoped, this was still the intention. Fourthly, I used AT to potentially explain why the key factors (identified by my research) influence AP (see Chapter 8, section 8.2, 8.3 and 8.4 respectively). Steps two, three and four represent the inductive dimension of my research. The ensuing sections discuss the outcomes from this aspect of my research.

7.2.2.1 Outcome 1: Interest in post-16 Physics

My study found that post-16 physics was not a popular option; only 4 students (from school-B) expressed any interest in post-16 physics. This finding strongly resonates with those reported in other studies (Archer et al., 2020; Abraham and Barker, 2015; Smithers and Robinson, 2009). For example, after reviewing the literature pertaining to interest in post-16 physics in England and in other countries, Smithers and Robinson (2009) concluded that: -

> 'Where it is possible to track physics participation at the A-level stage in other countries the trend, as in England...has been generally downwards' (Smithers and Robinson 2009:85).

Moreover, figures released by the Department for Education (DfE) reveal that the uptake of A-level physics is very low. For example, in the 2013/14 academic year, when I was in the early stages of my research, physics accounted for about 4% of the total A-level cohort (DfE, 2015). More recent figures released by the DfE show that interest in A-Level physics remains stubbornly low. For example, in the 2019/20 academic year, A-Level physics accounted for about 5% of the total A-level cohort in England (DfE 2018). As discussed in Chapter 1, this is concerning given the importance of physics in helping to produce a more technically literate workforce. The latter will increasingly drive economic growth and prosperity soon.

7.2.2.2 Outcome 2: Perception of Physics as a Discipline

Analysis of the quantitative data obtained from the questionnaires showed that a large proportion of the participants (93% from school-A and 89% from school-B) viewed physics as difficult and challenging from an academic standpoint. In addition, the qualitative data obtained from the focus group interviews strongly backed-up the quantitative data. When asked in the interview, 'how do you rate yourself in physics?' it quickly became apparent that many of the participants struggled with physics. The examples below reflect this struggle: -

- "Physics is really hard"$_{\text{schA}}$
- "Physics is tough"$_{\text{schA}}$
- "You've got to be clever to do physics"$_{\text{schB}}$

A review of the published literature shows that my research is not alone in reporting this outcome (Archer et al., 2020; Veloo et al., 2014; Gill and Bell

2011; Williams et al., 2003). For example, Archer et al., (2020) found that many of the students perceived science as academically challenging, especially the physics component.

In another example, Veloo et al., (2014) investigated the perceptions of students (aged 15 to 16) related to physics and concluded that, '...most students...perceived physics as for those who are intelligent and that Physics is a very difficult subject' (Veloo et al., 2014:37). These authors echo the findings of Francisco (2010), who carried out a comprehensive review of the published literature and concluded that physics is widely regarded as a difficult and challenging subject by many students in secondary schools. Moreover, the aforesaid researcher's investigation into the attitudes of Filipino and Australian students (aged 15 to 16) towards physics broadly supports my findings; Francisco (2010) reported that most of the participants in the study perceived physics as a difficult and challenging subject (Francisco, 2010).

In another example, after investigating the perceptions of secondary school students towards physics in England at KS4, Gill and Bell (2011) argued that physics teachers need to focus on helping their students '…to overcome the perception...that physics is a particularly difficult subject' (Gill and Bell, 2011:753). These studies highlight the general view within physics education that unfavourable perceptions of physics feed the development of less positive AP; the outcome from my research broadly supports this view. Interestingly, without being prompted either in the questionnaire or in the focus group interviews, several participants stated that mathematics made learning physics difficult; this view is reflected in the examples below: -

- “Physics is hard because there’s too much maths in it” $_{\text{schA}}$
- “The maths puts me off physics” $_{\text{schB}}$
- “There’s lots of equations in physics” $_{\text{schA}}$

A review of the published literature suggests that this unsolicited finding chimes with those reported in other studies (Wong, 2017; Haywood, 2016; Malik, 2016). For example, after carrying out a detailed review of the published literature Wong (2017) reported how a good proportion of students cited weaknesses in mathematics as a reason for their difficulties in science (including physics). Consequently, the aforesaid researcher suggested that closer, ‘…collaboration between science and mathematics departments may help students learning’ (Wong, 2017:232). Arguably, this need has become even more acute for two important reasons. Firstly, mathematical skills are now assessed as part of all GCSE qualifications in science (DfE, 2017). Secondly, the ‘...new science curriculum has introduced a significant increase in the use of mathematics…’ (Haywood et al., 2016:29). Interestingly, a recent review of the published literature suggests that the two disciplines are starting to forge closer ties in English secondary schools (ASE, 2016; Haywood et al., 2016). For example, a survey carried out by the ASE (Association of Science Education, 2016) reported the strengthening of links between these two disciplines. A future study could investigate if forging closer ties improves overall grades in GCSE physics and promotes the development of more positive AP.

7.2.2.3 Outcome 3: Role of the Physics Teacher

Analysis of the quantitative data showed that the bulk of the participants (83% from school-A and 88% from school-B) believed that their physics teacher encouraged and supported them when learning physics. In addition, the qualitative data broadly chimed with the quantitative data as illustrated by the examples below: -

- "Mr. [teacher's name] really tries to help us"$_{schA}$
- "He tries to explain everything"$_{schB}$
- "Sometimes, Mr. [teacher's name] explains too much"$_{schB}$

This outcome closely mirrors those reported in other studies which argue that the actions of the physics teacher can leave a lasting impression on students' perceptions of physics (Archer et al., 2020; Jansen et al., 2015; Logan and Skamp, 2013; Harrison and White, 2012). Moreover, it has been well documented that committed and enthusiastic teachers of physics can inspire, encourage and motivate their students and help inculcate more positive AP (Archer et al., 2020; Evans, 2014; Logan and Skamp, 2013; Harrison and White, 2012). For example, Archer et al., (2020) found evidence suggesting that science teachers strongly influence the development of their students' attitudes towards science.

In another example, a study commissioned by the Institute of Physics (IoP) found that supportive and encouraging teacher-pupil interactions strongly influenced the development of positive AP (IoP, 2014). Given the important role that a physics teacher can play in moulding and shaping AP, it is concerning to note how a dearth of physics graduates in England has led to '...a shortage of specialist…teachers…of physics in secondary schools' (Porter and Parvin, 2008: Executive Summary). As a result, many schools have been compelled to use non-specialist physics teachers to deliver the subject (Ratcliffe, 2014; Wellcome Trust, 2011; Smithers and Robinson, 2009). In fact, 'A recent DfE ...survey of teachers shows that a third (33.5%) of physics teachers in secondary schools do not have a degree in the subject' (Ratcliffe, 2014:1). Moreover, the problem appears to be global as noted by Smithers and Robinson, (2009), '…most countries…find it…difficult to recruit physics teachers...' (Smithers and Robinson 2009:82-83).

To attract more people into the teaching profession, especially in shortage subject areas such as physics and mathematics, the Government introduced the flagship Teach First programme (in 2002) to encourage graduates and professionals in STEM to enter the teaching profession (DfE, 2016). However, the latter has attracted much criticism, not least considering official figures released by the National Audit Office (NAO) in 2016. These figures show that at least one third of the teachers who qualified through this programme left the profession within the first five years (NAO, 2016).

The shortage of qualified physics teachers is a major cause for concern and needs to be addressed urgently.

7.2.2.4 Outcome 4(a): Perception of Physics Lessons

Many of the participants (91% from school-A and 83% from school-B) generally agreed that physics lessons were dull and difficult to follow. The above outcome is strongly mirrored in other studies; for example, after carefully reviewing the published literature related to student perceptions of secondary science education, Porter and Parvin (2008) reported that, 'In a survey of over 1,000 UK secondary students…over 50% said science lessons were boring…' (Porter and Parvin, 2008:10).

In relation to physics, Veloo et al., (2014) reported that physics is still largely perceived as a dull and boring subject with few engaging features. This is concerning given how the aforesaid perceptions inculcate negative attitudes towards physics (and science) in general (Bennett et al., 2014; Evans, 2014; Oquendo, 2012). In a notable exception, Archer et al., (2020) reported that students generally found science lessons engaging and fun. However, given that students aged 10 to 19 were involved in their programme, it is unclear which age group they are referring to in relation to this finding. It is also unclear which (if any) of the three subjects comprising science (physics, chemistry or biology) was perceived as especially engaging and fun.

Outcome 4(a) appears to be at odds with outcome 3; the latter suggests that physics teachers are enthusiastic about their subject and eager to help and support their students. Outcome 4(a) suggests that this may not be enough; it potentially needs to be backed up by lessons that are more fun and engaging. A future study could investigate this dimension further.

7.2.2.5 Outcome 4(b): Perception of Experiments in Physics

Analysis of the quantitative data showed that many participants (69% from school-A and 73% from school-B) enjoyed performing experiments. In addition, when asked in the focus group interviews which aspect of the lesson in physics they enjoyed the most, many of them cited performing experiments. The responses below reflect this overall view: -

- "Experiments are fun"$_{\text{schA}}$
- "I like doing experiments"$_{\text{schB}}$
- "Lessons go faster when we do experiments" $_{\text{schA}}$

These findings resonate strongly with those reported in other studies (Piper and Owen, 2016; Harrison and White, 2012; Reid, 2009a). For example, Porter and Parvin, (2008) reported how '…a survey of over 1,000 UK secondary students …found…that experiments are the best thing about learning science' (Porter and Parvin, 2008:10). In addition, they found strong evidence suggesting that male students tend to find experimental work more engaging, exciting and fun; other studies strongly echo these findings (Langley and Little, 2016; Aina, 2013).

Interestingly, some scholars question the effectiveness of physics experiments in deepening understanding (Shtulman and Valcarcel, 2012; Perry and Hoath, 2011). For example, Shtulman and Valcarcel (2012) suggest that the primary reason why many students look forward to experiments in physics is because they require very little mental effort to carry out. Nevertheless, despite these objections numerous studies argue that (in addition to being engaging and fun) physics experiments can be especially useful in consolidating learning and understanding (IoP, 2014; Aina, 2013; Reif, 2008; Reid and Serumola, 2006). Moreover, fun and exciting activities in physics are strongly linked with the development of more positive AP (Langley and Little, 2016; Aina, 2013). The findings from my study reinforce the general view alluded to in the published literature.

Given the importance of experiments in science, it is surprising that Hamlyn and Mathews (2017) found that on average, almost one third of secondary school students in England undertook science experiments only once a month. The authors' based this finding on a survey of over 4000 students (aged 15 to 19) attending several secondary schools across England. I did not ask the participants in my study how often they carried out experiments in physics and whether this was sufficient in their view. The reason I did not do this was because I had a relatively short time in which to complete the focus group interviews. A future study could investigate this dimension further.

7.2.2.6 Outcome 5: Real World Applications of Classroom Physics

Analysis of the quantitative data obtained from the questionnaire revealed that a large proportion of the respondents (93% from school-A and 87% from school-B) believed that physics taught in the classroom had little practical value or usefulness in the real world. This outcome closely resonates with those reported more widely in the published literature (Piper and Owen, 2016; Thomas, 2016; Wellcome Trust, 2011; IoP, 2008). For example, Veloo et al (2014) found that students who perceived physics as useful and relevant in the real world tended to harbour more positive attitudes whereas those who perceived physics as having little practical value harboured more negative AP: -

> 'For positive attitude, students perceived Physics as important and useful whereas for negative attitude, students claimed that Physics is not important and useful...' (Veloo et al., 2014:37).

In another example, the Wellcome Trust (2011) commissioned a large study to investigate (amongst other aspects) the perceived usefulness and relevance of classroom science (including physics) in the outside world and reported how: -

> '...the current research…confirms that pupils...have difficulties in making direct links and associations between what they learn at school, and how they apply this in everyday situations' (Wellcome Trust, 2011:6).

Their study argues that these difficulties contribute to the development of less positive attitudes towards science (including physics). They urge science teachers to make the link between classroom science and real-world applications more explicit. Castell et al (2014) advocate linking classroom physics with familiar technologies including laptops, mobile phones and the internet. For example, the mobile phone could be used to explain multiple concepts in physics. Microwaves connect the mobile phone to the overall communication network. In addition, as part of the electromagnetic spectrum, microwaves have much in common with the other members of the spectrum including radio waves; infrared waves; ultraviolet radiation, x-rays and gamma rays (Lincoln et al, 2007). Consequently, the physics teacher can use microwaves to explain the properties and behaviour of the other members as well. In addition, given that mobile phones contain chemicals that are harmful to living organisms, the physics teacher could ask students to develop solutions that could deal with unwanted phones (Lincoln et al., 2007). The aforesaid examples illustrate possible ways of raising student interest in physics and developing more positive AP. A future study could investigate if forging closer links between classroom physics and real-world physics does indeed translate into more positive AP.

7.2.2.7 Outcome 6: Awareness of Careers in Physics

Analysis of the quantitative data showed that only 9% of the participants from school-A and 13% from school-B believed that doing well in physics would get them a well-paid job in the future. Interestingly, when probed further in focus group interviews, it quickly became apparent that very few participants had a clear understanding of jobs, salaries and careers in physics and related occupations. The student responses below illustrate this point: -

- "What jobs can I do in physics?" $_{\text{schB}}$
- "How much do physics teachers get paid?" $_{\text{schA}}$
- "I don't think they [physicists] get paid a lot" $_{\text{schB}}$

A review of the wider literature suggests that my research is not alone in reporting this outcome. Several studies report that many students (aged 15 to 16) are largely unaware of the potential jobs, careers and salaries in physics and related occupations (Reiss and Mujtaba, 2017; IoP, 2014; Mujtaba and Reiss, 2012; Reiss et al., 2011). Many of these studies contend that this represents a major factor in the development of less positive AP (IoP, 2014; Mujtaba et al., 2013; Reiss et al., 2011). Moreover, they cite inadequacies in careers provision in schools as the root cause behind this situation (Archer et al., 2020; Langley and Little, 2016; Reiss et al., 2011; Raelin, 2008). For example, Archer et al., (2020) reported that information and advice linked to careers in science was often patchy and disjointed. In addition, they reported that students from more socially disadvantaged groups were generally less well informed about careers in science compared to students from more privileged groups. Indeed, in 2017 the DfE acknowledged the overall weakness in careers provision across the secondary school sector, ‘Careers guidance in schools has long been criticised as being inadequate and patchy’ (DfE, 2017:4). When it comes to physics, inadequate awareness of jobs, salaries and careers in physics (and related fields) appears to be especially acute. For example, an Ipsos MORI poll carried out in 2011 found that students (aged 15 to 16) were largely unaware of the potential jobs, salaries and careers in physics and related fields (Ipsos MORI, 2011).

To address this issue, the Institute of Physics (IoP) made the following recommendation, ‘we…recommend enhancing existing careers information…and the addition of job descriptions including salary estimations...’ (IoP, 2014:11). Secondary schools could consider working more closely with external organisations such as the IoP. The latter can provide information about jobs, salaries and careers in physics and related occupations (IoP, 2014; Shaha, 2011). In addition, through its extensive network, the IoP can signpost students to other providers of careers information such as the National STEM Network. A future study could investigate if raising overall awareness of jobs, salaries and careers in physics translates into more positive AP.

Summarizing, this study explored the key factors involved in the development of AP using a mixed methods approach. The quantitative data were obtained via questionnaire and the qualitative data were collected through focus group interviews; these key factors are shown below: -

Factor 1: Physics was generally perceived as an academically difficult and challenging subject. The mathematical dimension was cited as a major reason behind difficulties in learning physics. This factor (in conjunction with the mathematical dimension) promoted the development of less positive AP.

Factor 2: Overall, the participants believed that the physics teacher tried to motivate, encourage and support their physics learning. This factor promoted the development of more positive AP.

Factor 3: Aside from carrying out experiments, the participants largely perceived physics lessons as dull and difficult to follow. This factor promoted the development of less favourable AP.

Factor 4: Many participants believed that the skills and knowledge acquired in the physics classroom were of little use in the outside world. This factor promoted the development of less favourable AP.

Factor 5: Most of the participants had a limited awareness of jobs, salaries and careers in physics and related fields. This factor promoted the development of less positive AP.

7.2.3 Original Contribution

This dimension of my research has identified the attitudinal factors that strongly influence the development of AP; In doing so, it has added to the existing body of knowledge in the field of physics education. In addition, given that many of these factors resonate with those reported in other studies, my research has strengthened the generalization alluded to in the published literature, namely that the factors which strongly influence the development of AP also play a key role in the development of attitudes towards STEM subjects. A future study could investigate this dimension of my research further. Moreover, very few studies have applied a robust and coherent theoretical perspective to explain the relationship between GCSE grades in physics and AP. As we shall find out in the next chapter, using the theoretical perspectives afforded by Attitude Theory (AT), my study bridges this perceived gap in the literature.

7.2.4 Conclusion

Part II of Chapter 7 revealed the key factors that play an important part in the development of AP (as identified by my research). These factors include perception of physics as a subject of study; perceptions of the physics teacher; perceptions of physics lessons; perceptions of the relevancy and usefulness of classroom physics in the real world; overall awareness of jobs, salaries and careers in physics. The next section uses the theoretical perspectives afforded by AT to explain the relationship between GCSE grades in physics and AP.

Chapter 8 Attitude Theory

8.1 Introduction

This chapter employs the theoretical framework afforded by Attitude Theory (AT) in a novel way to potentially explain the relationship between GCSE grades in physics and Attitudes towards Physics (AP). The approach is novel in the sense that very few studies have applied a robust and coherent theoretical framework to explain why attitudes impact AA in STEM subjects. Focusing on secondary school physics, my study bridges this gap in knowledge and understanding. In addition, AT is used to potentially explain why certain attitudinal factors (identified by my study) strongly influence the development of AP; these factors were discussed in part II of Chapter 7. The chapter then spotlights the perceived strengths and weaknesses of AT and evaluates their impact on the theory's ability to potentially account for the positive correlation and to explain why certain attitudinal factors strongly influence the development of AP. Moreover, the chapter assesses the evidence suggesting that attitudes have the capacity to change under certain circumstances; this is done from the perspective of AT. The chapter then discusses the possibility of improving overall grades in GCSE physics by using the leverage afforded by the key attitudinal factors to shift AP in a more positive direction. The chapter begins with an explanation of the central tenets that underpin AT.

8.2 The Three Components Model (TCM)

Investigating the nature of attitudes has attracted interest from a wide range of academic disciplines; examples include sociology, psychology and political science. Consequently, 'The range and diversity of theories in the literature…on attitudes…is very large…' (Rajab, 2007:18). In the field of educational psychology, in which my study is grounded, AT is generally recognized as the dominant theory for explaining the nature of attitudes (Jain, 2014; Fiske and Taylor, 2013; Crano et al., 2010). In the current context, AT comprises Cognitive Dissonance Theory (CDT) and the Three Components Model (TCM).

Rosenburg and Hoyland (1960) were largely responsible for developing the Three Components Model (TCM); some scholars refer to it as the ABC (Affective, Behaviour and Cognition) model of attitudes. The core idea underpinning this model is that an attitude is a hypothetical construct that describes cognitive processes in our brain (Kayleigh, 2013; Nelson and Quick, 2013). This key notion is summarized by Cooper (2012) as follows: -

> 'Human cognitive processes…facilitate in the development of attitudes to social and physical objects, phenomena and experiences, collectively known as attitude objects' (Cooper, 2012:378).

Thus, given that an attitude is a hypothetical construct, it cannot be directly observed or measured. This means that any attempt to assess an attitude can only be inferential at best (Jovic et al., 2017; Kayleigh, 2013; El-Faragy, 2007). We can infer something about attitudes toward a given attitude object by carefully observing peoples' reactions, responses or behaviours toward it. This inference assumes that the reaction, behaviour or response broadly mirrors the hidden attitude (Fiske and Taylor, 2013; Brandt and Wetherell, 2012; Crano et al., 2010). Moreover, from the standpoint of the TCM, questionnaires and focus group interviews can be used to gauge attitudes, albeit indirectly. I used this approach to investigate the participants AP (see Chapter 3). The TCM contends that an attitude is made up of three key elements; these are shown Figure 13.

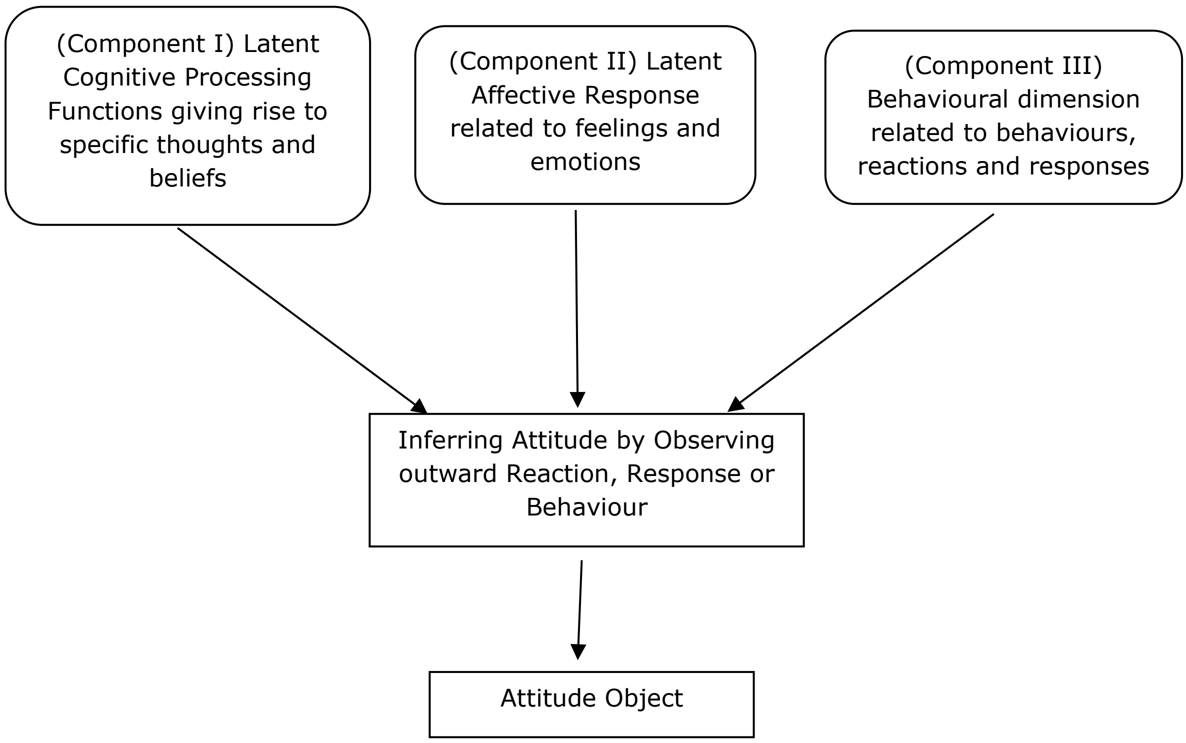


Figure 13: Principal Elements of the Three Components Model or TCM (Adapted from Eagly and Chaiken, 1998)

Figure 13 shows that attitudes primarily comprise cognitive, affective and behavioural components (Gross and Kinnison 2014; Mitchie, 2009; Ahlmali, 2008); Component I represent the cognitive functions related to rational thinking and logical reasoning (Krosnick and Petty, 2014; Vogel et al., 2014; Crano et al., 2010). In the context of my study, this component may be used to reflect on the following questions: Do I need a good grade in physics to achieve my career goals? Do I need a good grade in physics to study post-16 science in the sixth form? For example, just prior to the commencement of the focus group interviews, a participant mentioned that he was weighing-up the benefits of studying physics in order to become a pharmacist.

In contrast, Component II represents the cognitive functions linked to making subjective judgements about an attitude object (Gross and Kinnison, 2014; Rajab, 2007; Bohner and Wanke, 2002). Judging the attitude object favourably can promote the development of positive attitudes. Conversely, judging the attitude object unfavourably can promote the development of negative attitudes (Voget et al., 2014; Fiske and Taylor, 2013; Jarvis and Pell, 2004). For example, in the context of my study, the participants with more positive attitudes tended to find lessons in physics interesting and engaging. In contrast, those with more negative attitudes tended to find them dull and boring.

The third member of the TCM (Component III) represents the propensity to act or behave in a particular way toward a given attitude object (Gross and Kinnison, 2014; Eagly and Chaiken, 1998, 1993; Oppenheim, 1992). For example, analysis of the responses from the attitude questionnaires revealed that a significant number of students tended to lose focus and 'switch-off' in many of their physics lessons. From the perspective of the WMM, paying attention is an important first step in the learning or sense making process. Consequently, losing focus or 'switching off', representing the action or behavioural component, is not conducive to effective and efficient learning (Baddeley et al., 2014; Fiske and Taylor, 2013; Jarvis and Pell, 2004). The TCM contends that in order to form an attitude, we need '...knowledge about the object, or the beliefs and ideas (cognitive); a feeling about the object, or the like and dislike component (affective); and a tendency towards action, or the objective component (behavioural)' Reid (2006:4). Consequently, an attitude is borne out of '...an overall evaluation of an object that is based on cognitive, affective, and behavioural information' (Maio and Haddock, 2010:4). The TCM further contends that in order to create and maintain a particular attitude toward an attitude object, all three components must be broadly consistent with each other (Gross and Kinnison, 2012; Chu, 2008; Kida, 2008).

8.3 Relationship between GCSE Grades in Physics and AP

In an educational setting, the TCM contends that attitudes strongly influence our willingness to engage with a given subject (Nelson and Quick, 2013). For example, the amount of time and mental effort we invest in developing our understanding of a particular subject strongly depends on our attitudes towards that subject (Nelson and Quick, 2013). If our attitude toward it is positive, there is a good chance that we will study the subject keenly and committedly. In doing so, we may gain a deeper understanding of it and obtain a higher academic grade (Azjen et al., 2009; Maio and Haddock, 2007). In finding a positive linear correlation between GCSE grades in physics and AP, my study broadly confirms the outcomes predicted by the theory. In addition, my study found that participants with less favourable AP also tended not to access additional support when studying physics. They were less likely to attend additional classes or tutorials in physics; they were also less likely to engage in independent study. These actions and behaviours do little to develop learning and understanding in physics; indeed, they can hinder progress and potentially lead to weaker academic grades in physics. Other studies broadly echo these findings by reporting that individuals with less favourable attitudes towards STEM subjects are generally less inclined to stretch and challenge themselves and to take more ownership of their learning (Archer et al., 2012; Bong et al., 2012; Byrne, 2012).

In addition, there is also strong evidence in the published literature to suggest that students with unfavourable attitudes towards STEM subjects are less likely to persevere with their learning when experiencing challenges and difficulties (Afari, 2015; Bennett et al., 2014; Byrne, 2012). Indeed, several studies suggest that instead of regarding challenges in science (including physics) as opportunities to expand and develop their learning, these students are more likely to perceive them as barriers to learning

(Afari, 2015; Bennett et al., 2014; Byrne, 2012). Secondly, the TCM argues that self-efficacy is strongly influenced by attitudes; Bandura (1997) defines self-efficacy as '…beliefs in one's capabilities to organize and execute the courses of action required to produce given attainments' (Bandura, 1997:124). The TCM contends that as we progress through life, we develop certain beliefs or attitudes about what we can and cannot accomplish successfully (Domenech-Betoret et al, 2017; Guo et al., 2015; Byrne, 2012). In relation to succeeding in physics (in terms of attainment), the 'can' element represents high self-efficacy and is strongly influenced by positive attitudes. The 'cannot' element represents low efficacy and is strongly influenced by negative attitudes (Chan, 2009; Taconis and Kessels, 2009; Akey, 2006).

The theory argues that an individual with low self-efficacy in a particular subject will tend to avoid learning activities linked to that subject (Guo et al., 2015; Williams, 2010; Rajab, 2007). For example, an individual with low self-efficacy in physics may avoid or delay revising for an important test in physics. In not adequately preparing for the test, the individual is less likely to secure a good grade in the physics test. If that happens, it may promote the development of even less favourable AP and reduce self-efficacy further. Indeed, several studies have reported that when it comes to learning in general, attitudes and Academic Attainment (AA) are intimately connected and strongly influence each other (Archer et al., 2012; Bong et al., 2012; Byrne, 2012). Thus, finding a positive correlation between GCSE grades in physics and AP falls in line with the central tenets of AT. The next section applies the theoretical framework afforded by AT to explain why certain attitudinal factors play a pivotal role in the development of AP.

8.4 Impact of Key Factors on Attitudes towards Physics

Further analysis of the participant responses on the questionnaire and in focus group interviews showed that a large proportion of the participants found physics academically challenging. In particular, the heavy mathematical content involved in learning physics was a major factor behind the participants' difficulties in this subject. From the standpoint of the TCM, attitudes are generally formed by carefully evaluating our knowledge, experience and beliefs about the attitude object both objectively and subjectively. Analysis of the participants' responses revealed that most of the participants harboured less favourable AP.

Analysis of the quantitative data (from the questionnaire) and the qualitative data (from the focus group interviews) revealed that, in general, the participants felt that their physics teacher tried to motivate, encourage and support their learning and understanding of physics. From the standpoint of the TCM, the teacher's positive actions impact the affective component and promote the development of more positive AP (reflected in a higher score on the attitude questionnaire).

Aside from carrying out experiments, the participants generally perceived their physics lessons as dull, boring and difficult to follow. From the standpoint of the TCM, these broadly unfavourable evaluations of physics lessons are largely rooted in the affective component and will tend to promote the development of less favourable AP. Many participants believed that the skills and knowledge acquired in the physics classroom had little practical value in the outside world. From the perspective of the TCM, these broadly negative evaluations are chiefly embedded in the cognitive component. They can be especially detrimental to learning because they can reduce the incentive to invest time, effort and mental energy to study physics and demotivate the student. Collectively, these factors are more likely to promote the development of less favourable AP, resulting in a comparatively low grade in GCSE physics.

In addition, this study found that many of the participants had limited awareness of jobs, salaries and careers in physics and related fields. From the standpoint of the TCM, this situation can reduce the incentive to study physics and de-motivate the learner. Without a clear reward at the end of the learning process (in terms of a good salary or career for example), the model argues that there is less reason for the student to commit valuable resources (such as time, mental energy and effort) to study physics. Collectively, these factors can generate unfavourable overall evaluations (rooted in the cognitive component) and promote the development of less positive AP.

Analysis of the quantitative data from the questionnaire revealed that many of the participants received little or no encouragement to study physics from family or friends. From the standpoint of the TCM, this situation can adversely impact the affective component comprising attitudes. The model contends that strong support and encouragement from family and friends can motivate individuals to stretch and challenge themselves further in physics. Conversely, little or no support from those who are close to us emotionally can have the opposite effect. In the present context, it can lead to an unfavourable evaluation of physics and promote the development of less positive AP (as uncovered by this study). The next section considers the perceived strengths and weaknesses of the TCM and discusses their effects on the model's ability to explain the relationship between Academic Attainment in physics and overall AP.

8.5 Strengths and Weaknesses of the Three Components Model

Educational psychologists frequently turn to the TCM when explaining the nature of attitudes and discussing their impact on formal learning (Reid, 2011; Onwumere, 2009). I used the TCM to explain the positive correlation between GCSE grades in physics and AP. In doing so, I filled a perceived gap in knowledge understanding in the field of physics education. The principal strengths of the TCM fall into two broad areas. Firstly, educational psychologists generally agree that the TCM provides a relatively simple but effective way of understanding how attitudes towards different phenomena are formed and how they influence our interactions with these phenomena. Thus, in contending that attitudes are formed from just three primary ingredients namely cognitive, affective and behavioural, the TCM uses relatively straightforward ideas to describe and explain the hypothetical construct we call an attitude (Richetin et al., 2011; Norberg et al., 2007).

Secondly, the TCM makes specific predictions that can be tested through careful observation. Although an attitude cannot be directly observed, the model contends that we can infer something about the nature of the attitude, (favourable or unfavourable) by carefully observing how an individual responds, reacts or behaves towards an attitude object. These actions are assumed to reflect the individual's overall attitude toward the attitude object. Multiple studies have confirmed the predictions made by the model using this approach (Jain, 2014; Garland et al., 2010). Despite largely dominating the theoretical landscape when it comes to explaining the nature of attitudes, the TCM has attracted criticism from some educational psychologists. A minority of educational psychologists question the model's assertion that the three components comprising attitudes, (namely cognitive, affective and behavioural) are truly independent (Kayleigh, 2013; Reid, 2011). They suggest that these components may interact and influence each other to some degree; consequently, they argue that the model is under-developed in this respect (Jain, 2014; Nelson and Quick, 2013). Others point to the model’s perceived weakness in explaining why we experience some attitudes more intensely than others (Norberg et al., 2007; Eagly and Chaiken, 1998; 1993). They also criticize the model for not clearly explaining why some attitudes are formed more quickly than others (Jain, 2014; Garland et al., 2010). However, it is argued that these criticisms do not make any significant impact on the model’s ability to explain the relationship between GCSE grades in physics and AP.

Perhaps the biggest criticism of the model is that it assumes that our responses, reactions or behaviours towards an attitude object fairly and accurately reflect our hidden attitude toward that attitude object. Gross and Kinnison, (2014) explain this as follows, ‘…the three components model implies that the behavioural component will be highly correlated with the cognitive and affective components’ (Gross and Kinnison, 2014:181). However, not everyone is convinced that this assumption can be taken for granted as noted by Reid (2011), ‘the TCM...assumes that behaviour is an accurate measure of the hidden attitude...this [assumption] is open to question…’ (Reid, 2011:7). Critics argue that other factors (in addition to those included in the TCM) may influence how we act towards a given phenomenon (Knabe, 2012; Richetin et al., 2011; Rajab, 2007). Developing this argument further, Gross and Kinnison (2014) spotlight two factors that could potentially influence our actions as follows: -

> '… how we act in a particular situation will depend on…the…consequences of the behaviour…and…how we think others will evaluate our actions' (Gross and Kinnison, 2014:182).

In the context of this study, we can perhaps better understand the point that Gross and Kinnison (2014) are making by means of an illustration. Some of the participants in my study may have masked their positive AP when completing the questionnaire or in focus group interviews; they may have done this for any number of reasons. Perhaps they were concerned that if they expressed a liking for physics, especially in the focus group interviews, it may not go down well with their friends and peers.

If that was the case, then it was incorrectly assumed that the responses of the participants provided a fair and accurate reflection of their inner AP; this could potentially invalidate the outcomes from this dimension of the study. To reduce the likelihood of this event, I urged the participants to respond openly and frankly (when completing the questionnaire and in focus group interviews). I also made it clear that their data would be held in the strictest confidence. Moreover, I informed them that their identities would be anonymized and no one in their school (including teachers) would have access to their data. Consequently, the likelihood of this event happening was deemed to be very low. Moreover, numerous studies have used questionnaires and focus group interviews to gauge attitudes in a variety of fields (Cooper et al., 2012; Harmon-Jones et al., 2008). Despite these perceived weaknesses, the TCM continues to dominate the field of educational psychology (Jonas et al., 1997; Rushton et al., 1983). Indeed, the confidence in the ABC model (an alternative name for the TCM) is such that the ‘ABC model is one of the most cited…models of attitude’ (Jain, 2014:5).

Briefly summarizing, the TCM contends that attitudes comprise cognitive, affective and behavioural components. In addition, the theory argues that an attitude is a hypothetical construct and cannot be directly observed or measured. However, we can deduce the nature of the attitude by carefully observing how an individual responds or behaves toward a given attitude object. Although some educational psychologists question this assumption, the vast majority generally accept the central tenets of the model; moreover, they frequently refer to the TCM when investigating the nature of attitudes. The next section uses Cognitive Dissonance Theory (CDT) to discuss the possibility of improving GCSE grades in physics by shifting AP in a more positive direction.

8.6 Cognitive Dissonance Theory (CDT)

Festinger (1957) was largely responsible for developing Cognitive Dissonance Theory (CDT). The term cognitive dissonance refers to the mental discomfort that can arise when our behaviour or actions toward an attitude object do not chime with our attitudes towards that attitude object (Metin and Camgoz, 2011; Festinger, 1957). The mental discomfort can include feeling stressed, anxious or frustrated (Glasman and Albarracin, 2006; Elliot and Devine, 1994). The key elements comprising Festinger's (1957) model of cognitive dissonance are shown below.

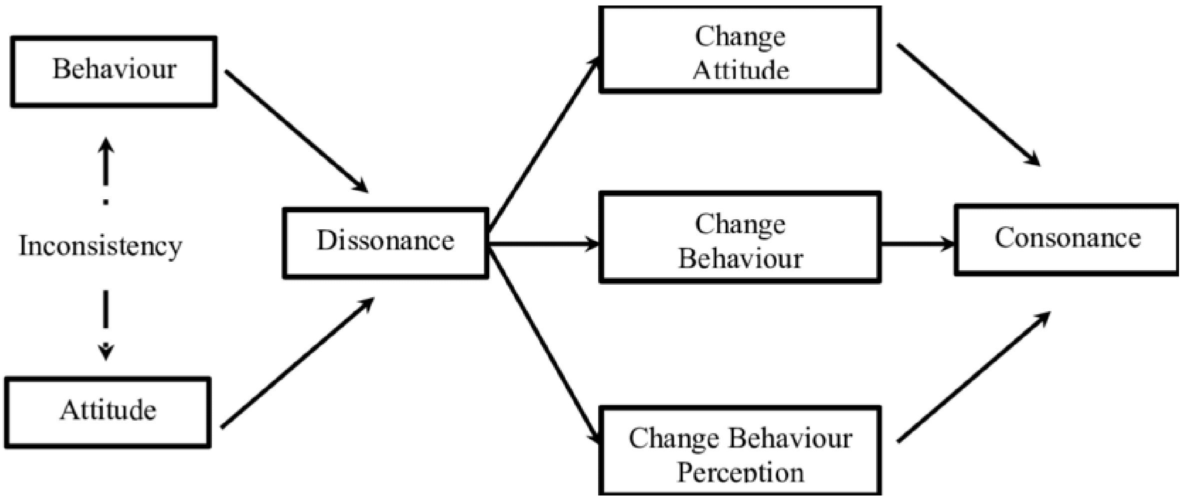


Figure 14: Cognitive Dissonance Model or CDM
(Adapted from Festinger, 1957)

CDT contends that, '…cognitive dissonance should be aroused when a person acts in a way that is contrary to his or her attitudes' (Harmon-Jones and Harmon-Jones, 2008:72). The ensuing psychological discomfort will compel the individual to find a way to alleviate the mental distress produced by cognitive dissonance (Cooper, 2012; Elliot and Devine, 1994).

From the standpoint of CDT, this can be done in the following ways: changing the attitude; changing the behaviour or perceiving the behaviour differently (Onwumere, 2009; McLeod, 2008). For reasons that are not fully clear in the literature, many individuals prefer to change their attitude toward the attitude object (Maich, 2013; Cooper, 2012; Harmon-Jones and

Harmon-Jones, 2008). This preference is summarized by Onwumere (2009) in the following terms: -

> ‘Attitude change is a major way of reducing dissonance...Experiencing dissonance, feeling uncomfortable with the previously held attitude position and working towards restoring the condition of balance and stability, the person will readjust the system of cognitions and adopt the attitude which makes him feel comfortable...’ (Onwumere, 2009:75-76).

Thus, ‘…. when dissonance exists….it provides the underpinning for attitude change…’ (Cooper, 2012:380). With respect to my study, how might we trigger cognitive dissonance and shift AP in a more positive direction? We can perhaps address this question through an example. Many of the participants in my study showed little interest in learning physics and rarely focused on physics lessons. This was partly because many of them found physics lessons generally dull and difficult to follow. Now imagine that the physics teacher adopts a new teaching approach that reverses this situation. Let us also imagine that many of the participants now find physics lessons more engaging, interesting and fun. From the perspective of CDT, the new positive feelings and behaviours towards physics are no longer compatible with the existing negative AP; this can potentially lead to cognitive dissonance. To reduce the mental discomfort associated with this condition, many of the participants may re-evaluate their existing AP and shift the latter in a more positive direction. Summarizing, CDT contends that attitudes can change provided there is a good enough reason or incentive to change them. Mental discomfort brought about by cognitive dissonance may compel individuals to re-evaluate their attitudes toward the object and adopt the attitude that reduces or ideally eliminates the cognitive dissonance.

8.7 Strengths and Weaknesses of Cognitive Dissonance Theory

CDT is a wide-ranging theory; in this study I have focused on the dimension of the theory that explains how cognitive dissonance can bring about a change in attitude towards an attitude object (Jones and Jones, 2008; Elliot and Devine, 1994). A particular strength of the theory is that it provides a relatively simple but powerful theoretical framework to explain how cognitive dissonance can bring about a change in the way people act, think, behave or make decisions (Kayleigh, 2013; Metin and Camgoz, 2011). Another important strength of CDT is that the outcomes predicted by the theory can be tested and confirmed or falsified (Mcleod, 2008; Glasman and Albrracin, 2006; Bohner and Wanke, 2002). Consequently, numerous studies have tested the outcomes predicted by CDT and generally confirmed them (Kayleigh, 2013; Jones and Jones, 2008; Elliot and Devine, 1994). Moreover, these studies hail from a wide range of academic disciplines including sociology, educational psychology and political science; thus, CDT enjoys widespread support (Metin and Camgoz, 2011; Onwumere, 2009; Harmon-Jones et al., 2008).

Despite dominating the field of educational psychology, CDT has been criticized by some educational psychologists. Critics argue that instead of changing their attitudes, some individuals may choose to tolerate the mental discomfort resulting from cognitive dissonance (Gawronski, 2012; Glasman and Albarracín, 2006). However, advocates of CDT contend that cognitive dissonance cannot be tolerated or suppressed indefinitely (Mai and Haddock, 2010; Egan et al., 2007). Eventually, the individual will select one of the three options to alleviate the mental discomfort; these include changing the attitude, changing the behaviour or perceiving the behaviour differently (Harmon-Jones et al., 2015; Kida, 2008). As noted earlier, for reasons not fully explained by CDT, changing attitudes towards the attitude object is often the preferred option for most people (Cooper, 2012; Lord, 1992). Importantly, this means that we can potentially use cognitive dissonance to shift AP in a more positive direction. When viewed alongside the correlational finding (showing a positive correlation between GCSE grades in physics and AP), it points to the possibility of improving GCSE grades in physics by targeting AP. A future study could investigate this aspect of my study further.

8.8 Conclusion

Educational psychologists generally agree that AT represents a powerful way of understanding the nature of attitudes. At its core, AT contends that an attitude is based on evaluating a given phenomenon from cognitive, affective and behavioural perspectives. Cognitive evaluation involves logical reasoning and rational thinking; for example, when forming AP, we may ask ourselves the following questions: Is studying physics worthwhile? Will it lead to a well-paid job? In contrast, affective evaluation involves recognizing our feelings and emotions towards physics. This may involve reflecting on the following questions: Do I enjoy studying physics? Do I find physics interesting and engaging? Do I gain satisfaction from studying physics? These objective and subjective evaluations strongly influence our AP. Viewed holistically, 'Attitudes…are likes and dislikes, favourable or unfavourable evaluations of…objects, people, situations…' (Hoeksema et al., 2009:662). In turn, the attitudes largely determine our actions and behaviours toward the phenomenon (or attitude object). In relation to physics, examples include the thoroughness with which we prepare for a physics test or how well we focus during physics lessons.

AT also contends that attitudes have the capacity to change provided there is a good enough reason to change them. Cognitive dissonance can potentially provide sufficient reason to bring about change in attitudes. This is because cognitive dissonance can create psychological discomfort; to eliminate this unpleasant mental condition, the individual can select one of three specific options; these include changing the attitude, changing the behaviour or perceiving the behaviour differently. A review of the literature suggests that most individuals change their attitude (Harmon-Jones et al., 2015; Cooper, 2012; Kida, 2008).

Crucially, given the positive correlation between GCSE grades in physics and AP, it might be possible to improve overall grades in GCSE physics by shifting AP in a positive direction via cognitive dissonance. A future study could investigate whether cognitive dissonance does indeed bring about a positive shift in AP and if this shift leads to an overall improvement in GCSE grades in physics.

Chapter 9 Conclusion and Suggestions for Further Research

9.1 Review of Research Aims

This thesis has investigated possible reasons why many students (aged 15 to 16) find physics academically challenging in England. I explored this problem from the perspective of two individual level cognitive factors (WMC and VSA) and one individual level affective factor (AP). Although a positive correlation between the aforesaid variables and Academic Attainment in STEM subjects is well known (see Chapter 2, part II), few studies have investigated the strength of the correlation between GCSE grades in physics and the aforesaid variables. Moreover, even fewer studies have tried to explain why there should be a positive correlation between STEM subjects and the aforesaid variables in the first place. Focusing on secondary school physics, my study bridged the gap in the literature on both counts. Although numerous studies have explored the attitudes of school age learners towards physics, especially females (see Chapter 2, part II) comparatively few have investigated the key factors driving the development of AP in all learners. In addition, the cognitive demands placed by the physics curriculum on WMC and VSA have also largely gone unexplored. My study filled the gap in knowledge and understanding on both counts.

9.2 Principal Outcomes from the Research

The Outcomes below show how my study bridged the gaps in the literature highlighted above.

Principal Outcome 1: I found a positive correlation of moderate strength between the individual level factor WMC and GCSE grades in physics

Principal Outcome 2: I found a moderate to strong positive correlation between the individual level factor VSA and GCSE grades in physics.

Principal Outcome 3: I found a weak to moderate positive correlation between the individual level factor AP and GCSE grades in physics

In addition, MRA showed that approximately 21% of the variance in the dependent variable (GCSE grades in physics) can be explained by the independent explanatory variables (WMC, VSA and AP) for $p<0.05$. This finding shows that collectively, WMC, VSA and AP exert a mild but significant influence on GCSE grades in physics.

Principal Outcome 4: I identified 5 factors that strongly influence the development of AP (shown in section 9.4 below).

Principal Outcome 5: I established the scope and depth of the cognitive load imposed on the WMC and VSA of the individual by the physics curriculum.

Principal Outcomes 1, 2 and 5 were explained using IPT, CLT and the WMM; Outcome 4 was explained using AT. I also discussed the possibility of improving overall grades in GCSE physics by: -

- Shifting AP in a more positive direction via cognitive dissonance.
- Improving or enhancing WMC and VSA through cognitive training.

9.3 Explaining Principal Outcomes 1 and 2

My study found those participants with a relatively large WMC and strong VSA tended to obtain higher grades in GCSE physics (Outcomes 1 and 2); these findings are consistent with those predicted by IPT. The theory contends that WMC (including its visual spatial component) is largely responsible for determining the scope and depth of learning taking place. An individual with a larger WMC can retain and process more information (in terms of volume and complexity) compared to someone with a more limited WMC. From the standpoint of IPT, an individual with a larger WMC is better able to cope with these cognitive demands. In addition, IPT contends that an individual who possesses strong VSA can process visual spatial information more efficiently and effectively compared to someone with relatively weak VSA. Having good VSA can be very useful when it comes to processing or making sense of information presented symbolically or pictorially; examples include graphs, sketches, diagrams and formulae. These representations are frequently used to help explain complex notions in physics.

In addition, given the concept-driven nature of the physics curriculum (Outcome 5), possessing superior VSA skills can be very useful when visualizing abstract ideas and concepts. For example, the physics curriculum requires students to be able to explain the '... phenomena of 'action at a distance' and the related concept of the field as the key to analysing electrical, magnetic and gravitational effects' (DfE, 2015:33). These fundamental forces of nature cannot be observed directly. That leaves us with two options; we either create our own symbolic representations of them or we interpret existing symbolic representations (sketch of a magnetic field in a physics textbook for example). In either case, IPT contends that the individual with stronger VSA is more likely to make better sense of these symbolic representations; a higher grade in physics may reflect this deeper understanding. In finding a moderate to strong positive correlation between VSA and GCSE grades in physics (Outcome 2), my study broadly confirms the outcome predicted by IPT.

Although IPT is very useful in explaining the positive correlation between GCSE grades in physics and WMC and VSA respectively (discussed in Chapter 5), it has little to say about the nature and size of the cognitive load imposed on WMC and VSA by the physics curriculum at secondary level; to address these important questions we need to turn to CLT. As noted in Chapter 6, CLT breaks down cognitive load into three distinct elements, namely Intrinsic Cognitive Load (ICL), Extraneous Cognitive Load (ECL) and Germane Cognitive Load (GCL). ICL primarily relates to the inherent complexity of the subject being studied; this complexity is generally reflected in the curriculum in formal education. For example, Johnstone

(2006; 1997; 1991) investigated the nature and size of the ICL arising from studying secondary school chemistry. As discussed in Chapter 8, Johnstone (2006) discovered that studying chemistry often involved making sense of abstract ideas and concepts at the macro, representational and sub micro level simultaneously; this placed a heavy ICL on WMC and VSA. Johnstone (2006) used CLT to argue that an individual with a relatively large WMC and good VSA was better placed to cope with these demands compared to someone with a relatively small WMC and more limited VSA. Moreover, the aforesaid researcher argued that individuals with more limited WMC and relatively weak VSA were at greater risk of overloading their WMC and VSA when studying chemistry. In the event of cognitive overload, Johnstone (2006) concluded that, as predicted by CLT, cognitive functions associated with learning and understanding generally broke down. Arguably, as discussed in Chapter 8, the cognitive demands involved in studying physics are broadly like those involved in studying chemistry. In addition, as discussed in Chapter 6, it is not possible to reduce ICL without compromising learning and understanding; this is because ICL represents the innate nature of the subject being studied.

Extraneous Cognitive Load (ECL) represents another important cognitive load that can impose itself on the cognitive processing capacity of the learner; the latter was discussed at length in Chapter 6. In the context of physics education, the latter can take myriad forms. For example, it can relate to the way information (such as facts) and instructions (such as how to carry out an experiment) are presented or conveyed to the student. If this is done without due care and attention, it can generate extraneous (or unwanted) cognitive load. Other ways of introducing ECL include ineffective and inefficient teaching methods and practices. In addition, poorly designed examination tests for example can also give rise to ECL; examples include questions with multiple sections or questions that contain superfluous information. Unfortunately, ECL can tie-up a large chunk of cognitive processing capacity unnecessarily.

Physics teachers can potentially reduce cognitive ECL by reviewing more closely how they plan learning activities and how they convey important information to students. However, this may be difficult to do in practice because of the enormous stresses and strains involved in teaching physics in the current secondary school setting. Examiners can also potentially reduce ECL by reviewing more closely the design and content of the GCSE examination in physics. This may be difficult though as examiners are not free agents. They must adhere to rules and regulations laid down by their profession. Bringing about a more concrete change in the design and content of examination tests for example may require input from multiple organisations, not least from regulatory bodies such as Ofqual and the JCQ.

Moreover, curriculum planners may need to reflect more closely on whether the physics curriculum places an excessive or unreasonable cognitive load on the WMC and VSA of the learner at KS4. However, this may not be simple or straightforward. For example, curriculum planners may be constrained by the demands of post-16 physics education, as well as political demands for more traditional curricula. This aspect of my research adds fuel to the wider debate in the field of secondary school physics education; the latter largely centres on the following questions: What should we teach in physics? How should we teach it? How should we assess learning and understanding?

Germane Cognitive Load (GCL) represents the third type of cognitive load that can be placed on WMC and VSA when studying physics; the latter was discussed at length in Chapter 6. Interestingly, from the perspective of CLT, the latter is considered highly beneficial to learning and understanding. Although GCL can initially place a high cognitive demand on WMC and VSA, it can reduce the overall cognitive load in the long term. This is because it facilitates the development of a schema or 'blueprint' for learning and problem solving; once developed, the latter can be stored in Long Term Memory (LTM). Consequently, when confronted with a broadly similar learning task or physics problem in the future, the individual can access the schema from LTM and reduce the cognitive load on WMC and VSA.

Importantly, CLT contends that ICL, ECL and GCL can combine to produce a cumulative effect; consequently, the total cognitive load on WMC and VSA can be very high when studying physics. Moreover, if the total cognitive load exceeds the cognitive processing capacity of the individual, learning and understanding can decline sharply. This means that individuals with relatively small cognitive processing capacity are especially susceptible to cognitive overload when studying physics. Interestingly, a review of the published literature suggests that stakeholders in physics education (including teachers, examiners and curriculum planners) are largely unaware that overtaxing WMC and VSA can adversely impact learning and understanding.

In summary, the theoretical perspectives afforded by IPT satisfactorily explain Outcome 1 (showing a moderate correlation between WMC and GCSE grades in physics) and Outcome 2 (showing a moderate to strong positive correlation between VSA and GCSE grades in physics). In addition, as discussed in Chapter 2, several studies have uncovered evidence suggesting that WMC and VSA can be improved or enhanced through targeted training. When viewed together, they point to the possibility of securing better overall grades in GCSE physics by targeting WMC and VSA.

9.4 Explaining Principal Outcomes 3 and 4

I found a positive linear correlation between GCSE grades in physics and AP (Outcome 3); this finding is consistent with that predicted by AT. The latter contends that our attitudes toward an attitude object strongly influence our actions and behaviours toward that attitude object. For example, in the context of my study, an individual's AP will strongly influence how much time, energy the individual is prepared to invest in learning physics. Thus, an individual with a more positive AP is likely to invest more heavily in learning physics compared to someone with a less positive AP. The relatively high level of investment may lead to a better grade in GCSE physics. Importantly, academic success may reinforce positive AP and vice versa; the relationship is bi-directional.

In addition, my study identified the following factors as strongly influencing the development of AP: -

- Physics was generally perceived as a difficult and challenging subject. Moreover, the mathematical content involved in learning physics was cited as a major source of these difficulties.
- Physics lessons were generally perceived as dull and difficult to follow. However, the experimental component of the physics lesson was regarded more favourably in general.
- Many felt that the physics teacher supported and encouraged them in the physics lesson.

- Awareness of jobs, salaries and careers in physics and related fields was very limited.
- Few could link physics taught in the classroom with practical applications in the real world.

In addition, very few of the participants intended to pursue post-16 physics. As discussed in Chapter 9, physics teachers can also play an important role in shifting AP in a more positive direction and thereby potentially increase interest in post-16 physics. In relation to the factors shown above, physics teachers may consider: -

- Planning more of the teaching around experiments.
- Liaising closely with mathematics teachers to ensure that students have sufficient mathematical skills to access physics.
- Making more explicit connections between classroom physics and real-world applications.
- Incorporating a wide range of multimedia approaches that make physics lessons more engaging, interesting and fun.
- Promoting 'a can do' mindset.

In addition, as discussed in Chapter 7, raising awareness of jobs, salaries and careers in physics (and related fields) may also help promote the development of more positive AP. Summarizing, my study found a positive correlation between GCSE grades in physics and AP (Outcome 3). It also identified five factors that strongly influence the development of AP (Outcome 4). Moreover, AT contends that AP can potentially be shifted in a more positive direction via cognitive dissonance. When viewed together, they strongly suggest that we can improve GCSE grades in physics by shifting AP in a more positive direction via cognitive dissonance. This may lead to better uptake of post-16 physics and re-energize interest in studying physics at degree level. The next section spotlights the limits of my research; it also suggests how future studies can go beyond these limits. In doing so, they can expand knowledge and understanding in the field of educational psychology.

9.5 Limits of the Research

The original contribution my research has made in extending knowledge and understanding in the field of physics education must be viewed against the backdrop of its limitations; the latter fall into five broad areas.

Firstly, although numerous studies have reported that WMC and VSA can be enhanced through mental training, I did not test these claims. In addition, I did not investigate if cognitive dissonance shifted AP in a more positive direction. Consequently, I could not confirm if improving the aforesaid variables produced an overall improvement in GCSE grades in physics. In addition, MRA shows that in order to obtain a whole grade improvement in GCSE physics, at least one of the following changes must take place: -

- The average WMC score must increase between 2 and 5 units (on the DSBT).
- The average VSA score must increase by 11 units (on the PSVT: R).

- The average AP score must increase by 50 units (on the Questionnaire).

At this stage, it is unclear if the aforesaid variables can be improved by the respective amounts. Nevertheless, the correlational outcomes suggest that all learners can potentially benefit from improving their overall WMC, VSA and AP. Those on the cusp of attaining a better GCSE grade in physics may benefit the most. This dimension could be explored more deeply in a future study. It is also not clear if mental training leads to short lived or long-lasting improvements in WMC and VSA; educational psychologists are still keenly debating this point. If they are long lived, targeting WMC and VSA to raise GCSE grades in physics may be justified in the long term.

Interestingly, as discussed in Chapter 5, evidence from the field of neuropsychology suggests that the effects may be long lasting, especially if the mental training is repeated on a regular basis. However, more research is needed in this area; perhaps educational psychologists could collaborate more closely with neuropsychologists in this respect. The literature review suggests that cognitive dissonance tends to produce a permanent shift in attitudes. Thus, targeting AP (via cognitive dissonance) to improve AA in physics represents a potentially viable option. Secondly, MRA revealed that about 21% of the variation in GCSE grades in physics can be explained by the cognitive-affective variables. The notion of science capital may have been useful in understanding how social background factors influence AA in physics and gone some way toward accounting for the variation in GCSE grades in physics not explained by the cognitive-affective variables. However, I did not consider the potential impact of science capital on AA in physics. This was mainly because my literature review had focused on individual-level factors (in keeping with the aims of my research). Consequently, my awareness of how broader social factors could be conceptualised in ways relevant to my research was limited. A future study could incorporate the concept of science capital in both the design of data-collection instruments and in the analysis of AA in physics. However, although this would enhance understanding of the processes involved, I do not believe that my findings would be fundamentally altered by this extension in the research design.

Thirdly, aside from school-age students, I did not approach other key stakeholders in physics education; examples include physics teachers, curriculum designers and examiners. Consequently, I did not ascertain their views on the extent to which the cognitive load (arising from the science curriculum) and attitudes impact AA in physics. This was not done because as a sole researcher holding down a full-time job, I had limited resources and a relatively short time period in which to collect and analyse the primary data. However, a future study could be more inclusive when building on the findings from my study.

Fourthly, in potentially explaining the correlation between AP and GCSE grades in physics, I relied on the theoretical perspectives afforded by AT.

Consequently, I ignored alternative theoretical perspectives regarding the nature of attitudes and the extent to which they could potentially influence AA in physics. Examples include TPB (Theory of Planned Behaviour) and MODE (Motivation and Opportunity as Determinants). In their defence, both the TCM and CDT are widely acknowledged in the field of educational psychology as leading theories in explaining the relationship between AA and attitudes. Similarly, I used IPT to potentially explain the positive correlation between WMC and VSA respectively with GCSE grades in physics. Consequently, I did not consider alternative theoretical perspectives that could possibly have explained the correlational outcomes revealed by my study. Examples include Behaviourist, Humanist and Constructivist Theories of Learning. However, in its defence, IPT is widely regarded as a powerful theory for explaining the cognitive functions linked to learning and understanding in the field of educational psychology. Nevertheless, a future study could investigate whether an alternative theory can better explain the correlational outcomes revealed by my study.

Finally, it should also be borne in mind that my beliefs, values, opinions and experiences may have made an impression on the research; for example, they may have influenced: -

- How I identified the research problem.
- The way I carried out the research.
- How I analysed and interpreted the quantitative and especially the qualitative data.

- How I reached my conclusions.
- The way I chose to edit and report my research findings.

However, from the standpoint of post positivism, in which my study is grounded, it is expected that I will probably stamp my subjective nature on the research process either consciously or subconsciously; this has advantages and disadvantages. For example, a potential disadvantage is that I may emphasize outcomes that I personally deem to be important even though the evidence may not necessarily warrant it. Conversely, given that I have taught physics for nearly forty years, my knowledge and experience may have proved advantageous when analysing and interpreting the raw data.

9.6 Summary of the Original Contribution

I have contributed to knowledge and understanding in the field of physics education in the following ways: -

1. I found a positive correlation between GCSE grades in physics and two individual-level cognitive factors namely, WMC and VSA. The correlation is probably causal with the cognitive variables representing 'the cause' (respectively) and GCSE grades in physics representing 'the effect'.
2. I found a positive correlation between GCSE grades in physics and the individual-level affective factor AP; this correlation is probably bidirectional.

3. I used IPT, CLT and WMM to explain the positive correlation between GCSE grades in physics and WMC and VSA.
4. I used AT to explain the correlation between GCSE grades in physics and AP.
5. I identified several key factors that strongly influence the development of AP.
6. I explored the cognitive load on WMC and VSA arising from the science curriculum when studying physics at KS4.
7. I discussed the possibility of improving overall GCSE grades in physics by shifting AP in a more positive direction and by enhancing WMC and VSA through cognitive training.

9.6.1 Degree of Confidence in the Key Findings from my Research

My research philosophy is firmly grounded in the post-positivist paradigm. Fundamentally, I believe that all knowledge is theory-laden and contextually dependent, so provisional and open to change. The research was conducted in two specific schools in the north of England, using relatively small samples, and operating under the constraints of real-world research with busy students and professionals. Within the post-positivist paradigm, the resulting questions concerning generalisability and transferability are acknowledged and regarded as essential components of the research process, rather than hidden or explained away. The ensuing discussion should be viewed with this in mind.

Convenience sampling was used to obtain the aforesaid samples (see Chapter 3, section 3.2.6). The risk of obtaining a biased sample via convenience sampling is relatively high (Wilcox, 2017; Field, 2014; Nolan and Heinzen, 2011). In addition, the samples were relatively small (n=45 and 55 respectively). From a statistical standpoint, small samples tend to give larger SEM and CI values, and this can reduce confidence in their representativeness (Wilcox, 2017; Field, 2014; Nolan and Heinzen, 2011). Consequently, we must be cautious when making inferences and drawing conclusions about the wider population based on small samples obtained through convenience sampling. However, despite these potential drawbacks, I am reasonably confident in my findings showing a statistically significant positive correlation between GCSE grades in physics and the cognitive-affective variables respectively. Three broad reasons mainly underpin this confidence.

Firstly, from a statistical perspective, a sample size comprising at least 30 participants is sufficient for carrying out correlational analysis (Field, 2014; Nolan and Heinzen, 2011). Secondly, theories from the field of educational psychology (IPT and AT) predict a relationship between AA in physics and the aforesaid cognitive-affective variables respectively (see Chapters 5 and 8). Thirdly, several studies have reported finding a link between GCSE grades in STEM subjects and WMC, VSA and attitudes respectively (see Chapter 2, Parts I and II). Collectively, they strengthen confidence in the credibility and generalisability of the findings from this dimension of my research. I am also reasonably confident that my research goes some way toward establishing a causal relationship between the cognitive variables (‘the cause’), and GCSE grades in physics (‘the effect’). This is because these findings meet most of the causality criterion suggested by Taris and Kompier (2016); see Chapter 7, section 7.1.7. In the case of GCSE grades in physics and AP, the relationship is probably bidirectional. This is because several studies have reported finding a bidirectional association between AS and AA in science (see Chapter 8, section 8.3). In contrast, I am less confident about the generalisability of the factors that influence AP (see Chapter 7, Part II). I identified these factors after analysing the attitudinal data. Even though I tried to remain impartial and objective, my personal bias and prejudice may have adversely influenced the way I analysed the aforesaid data, especially the qualitative component, and ‘muddied the waters’.

9.7 Research Journey

I am a full-time physics teacher with almost forty years’ experience working in state funded secondary schools across West Yorkshire. I get immense satisfaction from teaching physics and helping students develop their knowledge and understanding of this fascinating subject. However, over the years many students have told me that they find physics difficult and challenging. I wanted to find out why this was the case and what could be done to help students overcome their difficulties in physics. I chose the University of Huddersfield to pursue my research because I had completed a master's degree at the University some fifteen years earlier.

The research was unlike anything I had done before and involved developing a whole raft of skills and competencies. I had to plan and organise my research carefully and use my limited resources more effectively and efficiently, not least my time budget. I had to set milestones and keep a research diary to track my progress. I also had to develop my critical thinking skills and improve my writing skills. For example, my initial writing tended to be overly didactic and repetitive. However, with practice and constructive feedback from the supervisors, my writing became more scholarly and critical. Supported and guided by my supervisors, I also developed skills and competencies in other areas. For example, I became better at determining the relevancy of an article or journal by reading the abstract and the conclusion; previously, I would read the whole article.

Initially I wanted to understand the problem using multiple theoretical perspectives. I also wanted to collect large amounts of quantitative and qualitative data. However, my main supervisor suggested that I was being over-ambitious and that I needed to reduce the scope of my research in order to make it more manageable and achievable. Taking this advice on board, I revised my research aims and objectives. I now understand more clearly how the research process is made up of several key elements. In the case of my research, these were broadly as follows: identify and define the problem; review the literature pertaining to the problem; design the research; carry out the research; analyse and interpret the data and communicate the research findings.

I also recognise how the research design can go a long way toward establishing the reliability and validity of the findings from the research. The stages comprising my research design broadly chimed with those articulated by Saunders et al., (2007); they are summarised below: -

- Research Philosophy - My research was embedded in post-positivism.
- Research Approach - I utilised both deductive and inductive dimensions in my research.
- Research strategy - I used surveys, interviews and psychometric tests.
- Time Horizon - I used a cross-sectional time horizon.
- Data Collection Techniques - I used a questionnaire, two focus group interviews, and two psychometric tests.

I also realise how important it is to make sure that an overall argument or 'golden thread' features prominently in the thesis. This helps weave the different elements comprising the thesis into a coherent whole. Moreover, it helps the reader to understand the point of the research. In the case of my research, the organising argument was that we can potentially improve AA in physics (at the lower tier of secondary education) by targeting the cognitive-affective variables linked to WMC, VSA and AP respectively.

I am also more acutely aware that the research process is not necessarily linear. For example, I often returned to previous chapters to add or amend material. Also, throughout the research journey, I continuously reviewed the literature to make sure that I was aware of the latest developments in my field. In fact, I continue to review the literature in my field. I also understand that the way in which the research is framed will largely determine the type of literature that is reviewed. In the case of my research, I mainly focused on literature in the field of educational psychology. Consequently, I had little awareness of literature in other fields that may have been relevant to my research. Specifically, I was unaware of the notion of science capital and its potential impact on AA in physics (Archer et al., 2020).

At times, I did feel isolated and detached from a research community. For example, aside from prescribed meetings with my supervisors (once a month on average), I had little contact with fellow researchers, especially those at my university. Moreover, as a part-time researcher, I found it difficult to access the full research provision offered by the University. For example, I could not take part in the weekly Postgraduate Research Forum because I was normally working at that time. To help alleviate this situation I attended EdD classes in the evenings; I even completed the EdD assignments for feedback. In addition, I attended lectures and conferences (organised by my faculty) whenever possible.

I also had to deal with unforeseen events. For example, part way through the research, my main supervisor left unexpectedly. Even though my second supervisor continued to advise and support me, this was still a difficult time for me. About three months later, another excellent main supervisor was assigned to me. The Covid-19 pandemic also introduced its own difficulties for me both as a researcher and as a teacher. For example, I had to convert my classroom lessons to online lessons and create digital resources for my students. This consumed a large chunk of time that I had set aside for my research. However, my belief that I was doing something potentially important helped sustain me through these challenging times.

9.8 Final Thoughts

We should all be concerned about why many students find secondary school physics academically difficult and challenging. This is because physics underpins scores of technical disciplines including electronics, mechanical engineering, medical physics, telecommunications – the list is almost inexhaustible. The physics sector also makes a sizable contribution to the UK economy. In addition, as we progress deeper into the 21st century, modern societies will become increasingly dependent on a technically proficient workforce for continued economic growth and prosperity. Physics education is ideally suited for this task given how it develops analytical thinking skills and problem-solving abilities. In addition, global issues such as climate change and the depletion of natural resources will require novel technical solutions; individuals who are well versed in physics can potentially make a strong effort towards developing these technical solutions. Unfortunately, physics grades continue to remain sluggish and interest in post-16 physics shows few signs of improving. This situation needs to be reversed sooner rather than later.

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Appendices

Appendix 1: Digit Span Backwards Test (DSBT)

The DSBT was used to gauge the WMC of the participants who took part in my study

DIGIT SPAN BACKWARD TEST

IN THIS TEST WE WILL FIND OUT HOW WELL YOU CAN REMEMER AND RECALL INFORMATION JUST GIVEN TO YOU

ALL OF YOUR RESPONSES AND YOUR IDENTITY WILL BE KEPT STRICTLY CONFIDENTIAL AND NOT REVEALED TO ANYONE

YOUR GRADES WILL NOT BE AFFECTED

Name: ____________

Year Group: ____________

Gender: ____________

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Instructions to the Participants

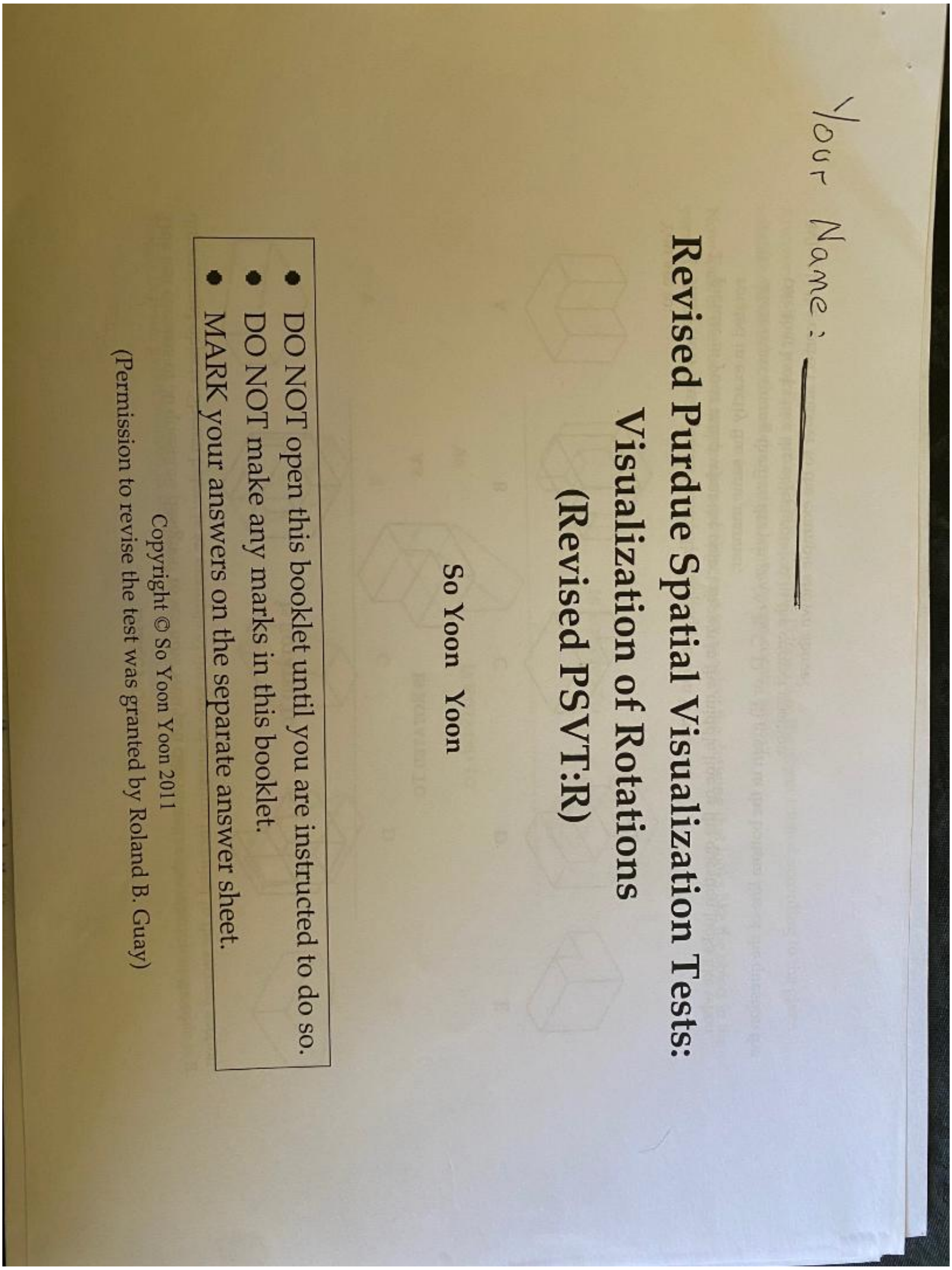
I am going to read out some numbers. You must listen carefully to my voice and not interrupt me or write anything down. When I get to the end of the list of numbers, I will say "write"- you will then have exactly 5 seconds to write down the numbers in the boxes provided in REVERSE ORDER in row (a) of the worksheet. I will then say "next" and repeat another longer list of different numbers. As before, after I have finished the list of numbers, I will say "write" and you will fill in the boxes with the digits in REVERSE ORDER in row (b). I will then say "next", and the process will begin again. This will continue until we get to row (h) and then we will stop. That will be the end of the test. The whole test will be repeated twice. Altogether it will take about 20 minutes to complete the test three times.

Discrete Number Generation

(a)	3	9							
(b)	2	6	4						
(c)	3	8	5	7					
(d)	6	8	1	9	2				
(e)	5	2	8	3	7	4			
(f)	2	7	5	9	8	1	3		
(g)	7	9	1	4	2	8	3	5	
(h)	4	9	5	3	6	2	4	7	1

Appendix 2: Extract of Purdue Spatial Visual Test of Rotations (PSVT: R)

The PSVT: R was used to measure the VSA of the participants who took part in my study.



Your Name: ____________

Revised Purdue Spatial Visualization Tests:

Visualization of Rotations

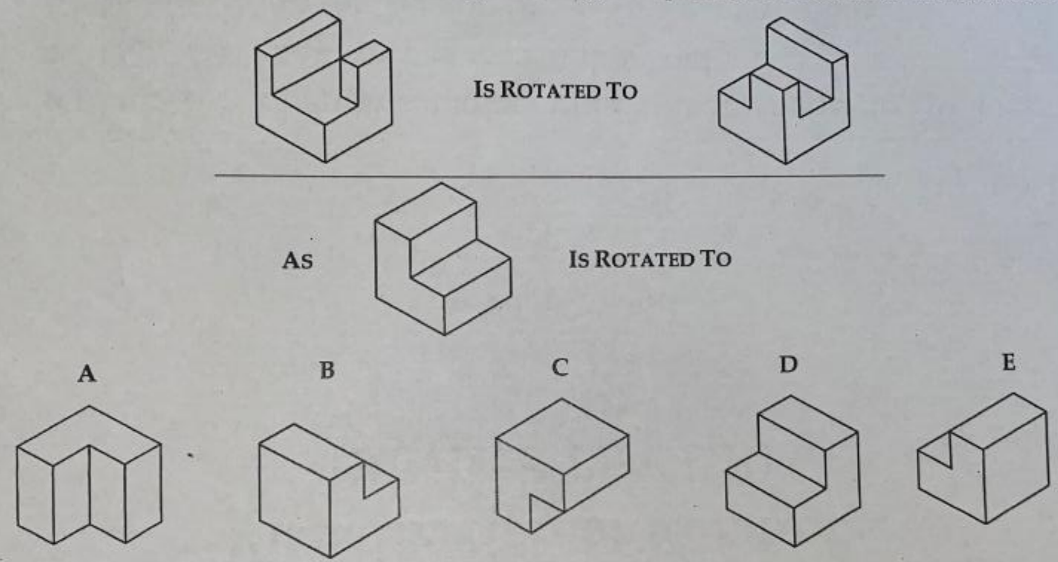
(Revised PSVT:R)

So Yoon Yoon

- DO NOT open this booklet until you are instructed to do so.
- DO NOT make any marks in this booklet.
- MARK your answers on the separate answer sheet.

DIRECTIONS

This test consists of 30 questions designed to see how well you can visualize the rotation of three-dimensional objects. Shown below is an example of the type of question included in the second section.



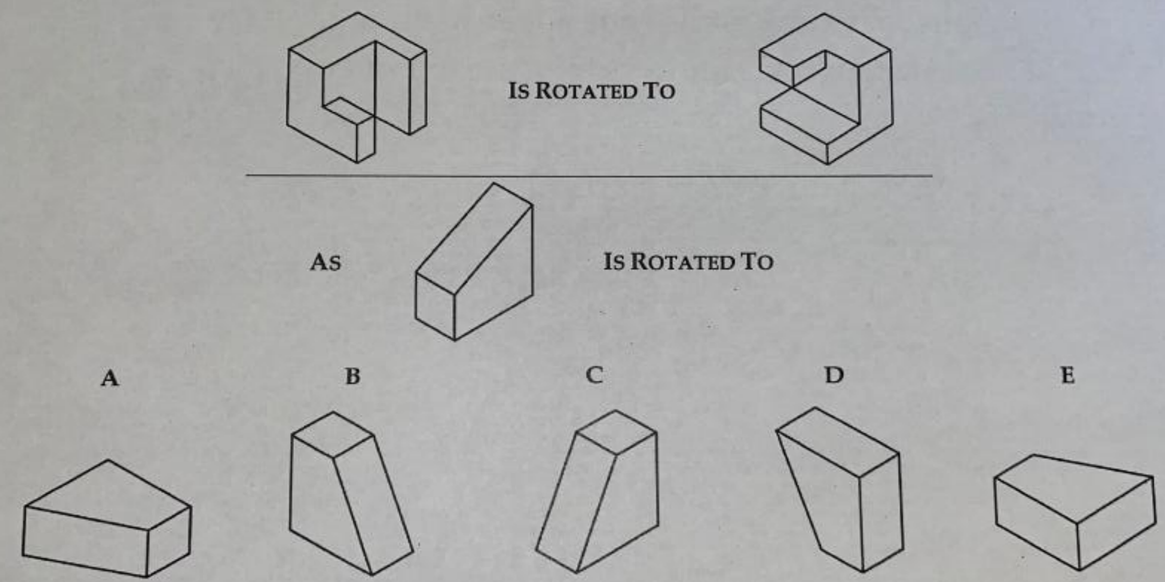
You are to:

1. study how the object in the top line of the question is rotated;
2. picture in your mind what the object shown in the middle line or the question looks like when rotated in exactly the same manner;
3. select from among the five drawings (A, B, C, D, or E) given in the bottom line of the question the one that looks like the object rotated in the correct position.

What is the correct answer to the example shown above?

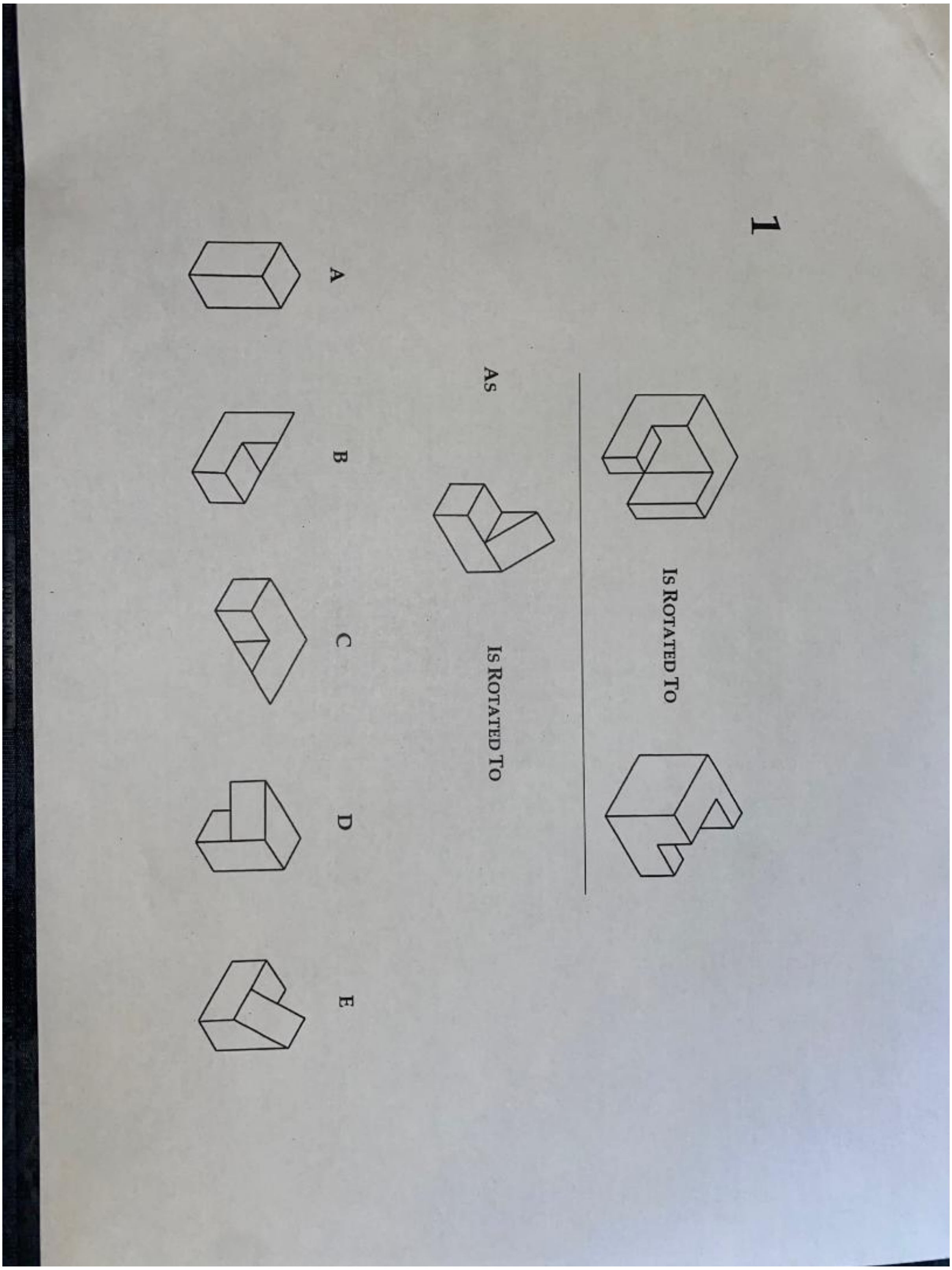
Answers A, B, C, and E are wrong. Only drawing D looks like the object rotated according to the given rotation. Remember that each question has only one correct answer.

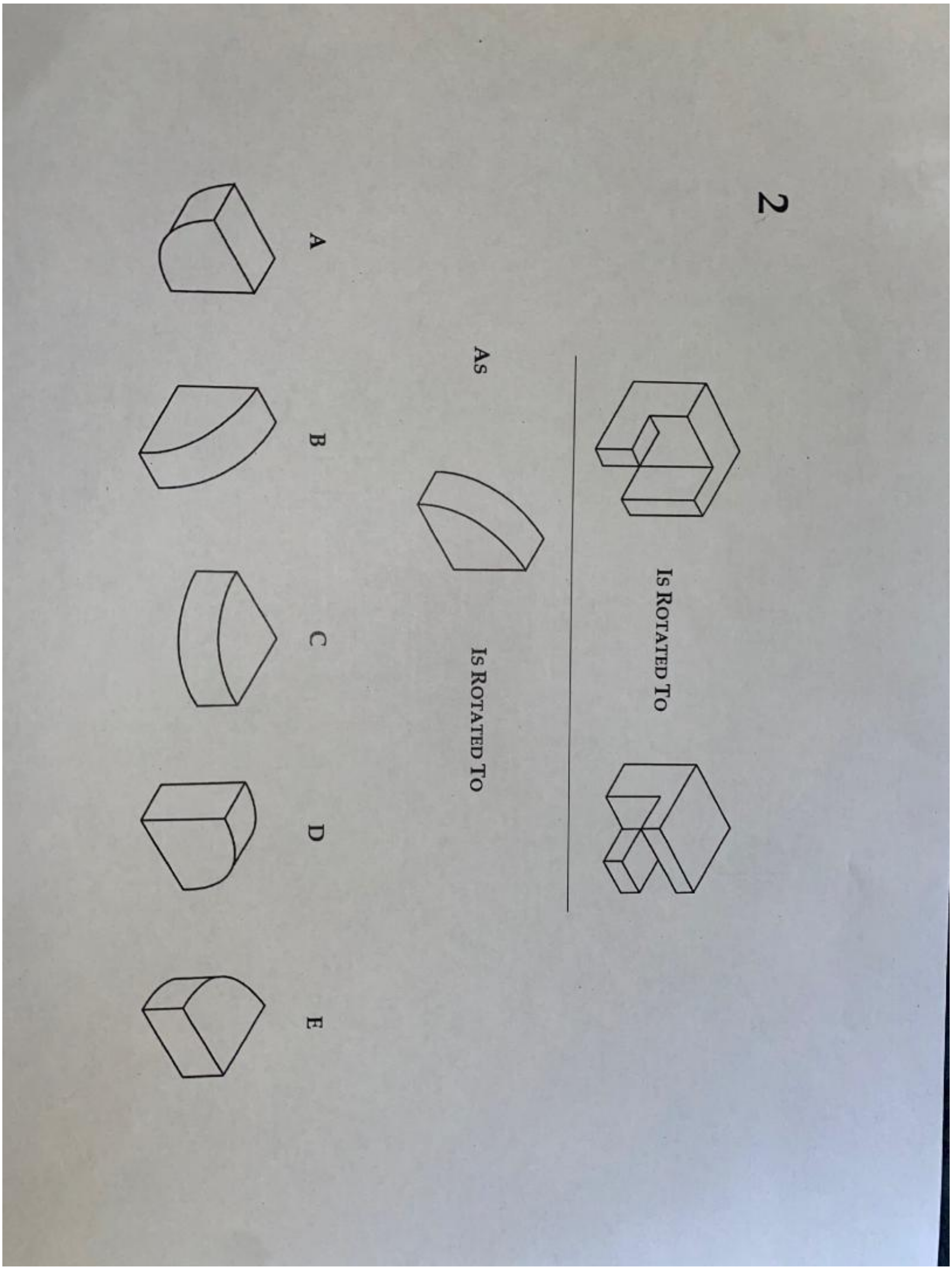
Now look at the next example shown below and try to select the drawing that looks like the object in the correct position when the given rotation is applied.



Notice that the given rotation in this example is more complex. The correct answer for this example is B.

- DO NOT make any marks in this booklet.
- Mark your answers on the separate answer sheet.
- You will be told when to begin.


1
IS ROTATED TO
AS
IS ROTATED TO
A
B
C
D
E


2
Is Rotated To
As
Is Rotated To
A
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C
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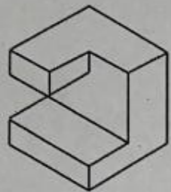
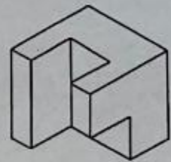
E

3



Is Rotated To



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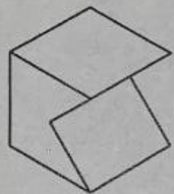
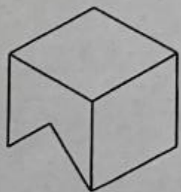
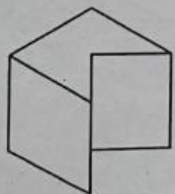


Is Rotated To

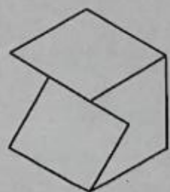
A



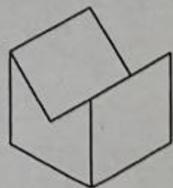
B



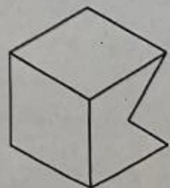
C



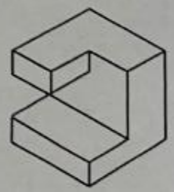
D



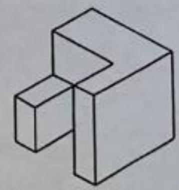
E



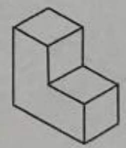
4



Is Rotated To



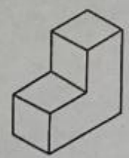
As



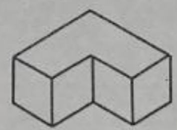
Is Rotated To

A

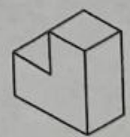
B



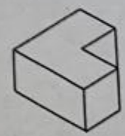
C

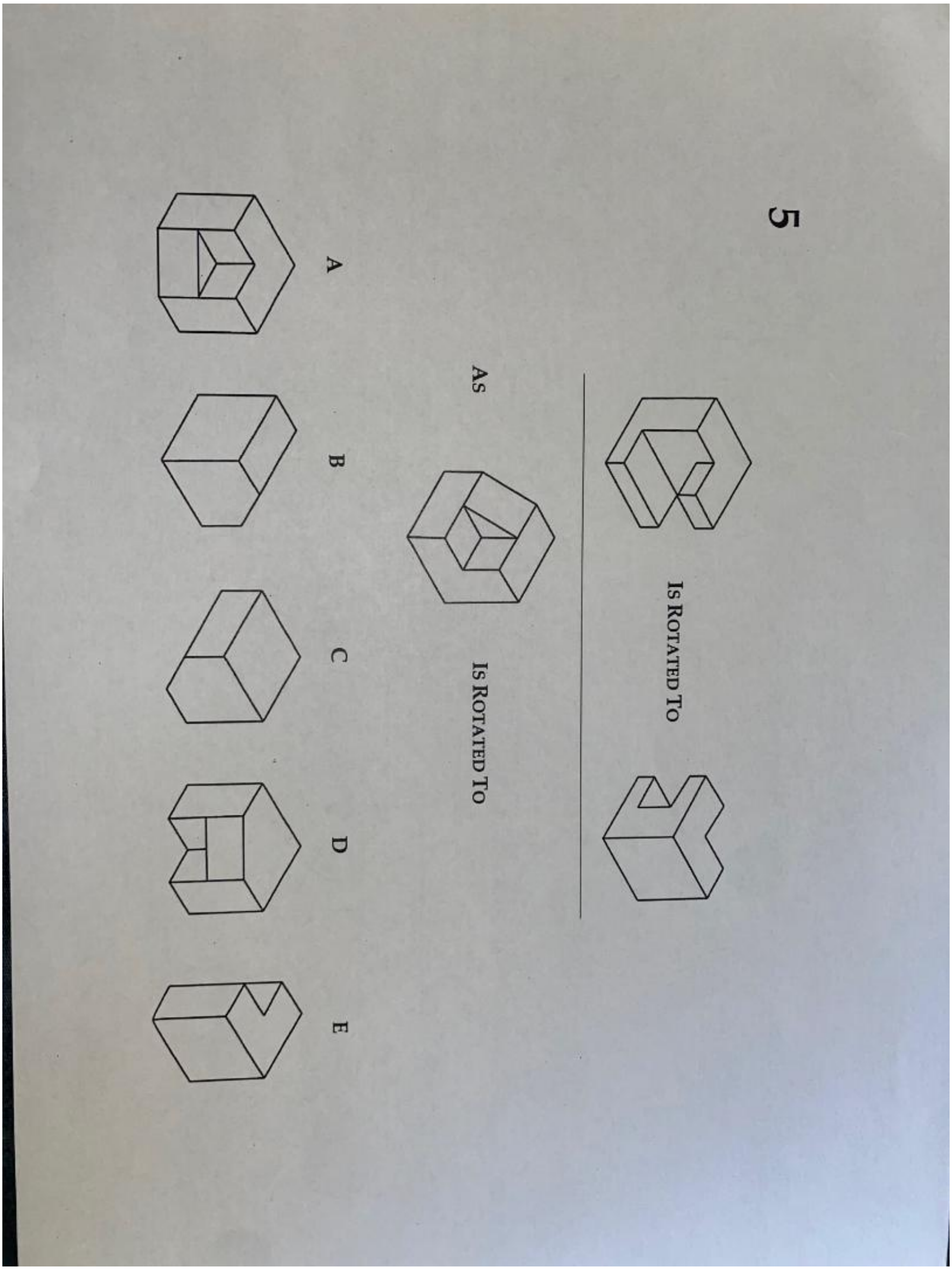


D



E




5
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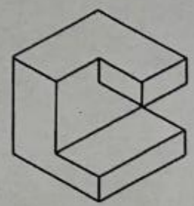
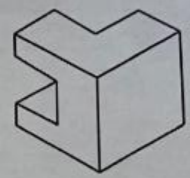
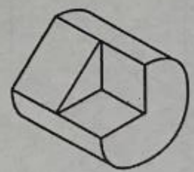
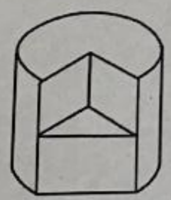
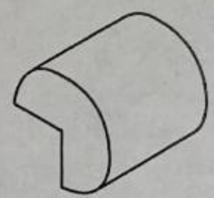
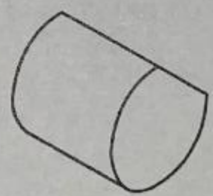
6

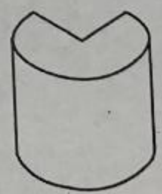
 IS ROTATED TO 

AS  IS ROTATED TO

A 

B 

C 

D 

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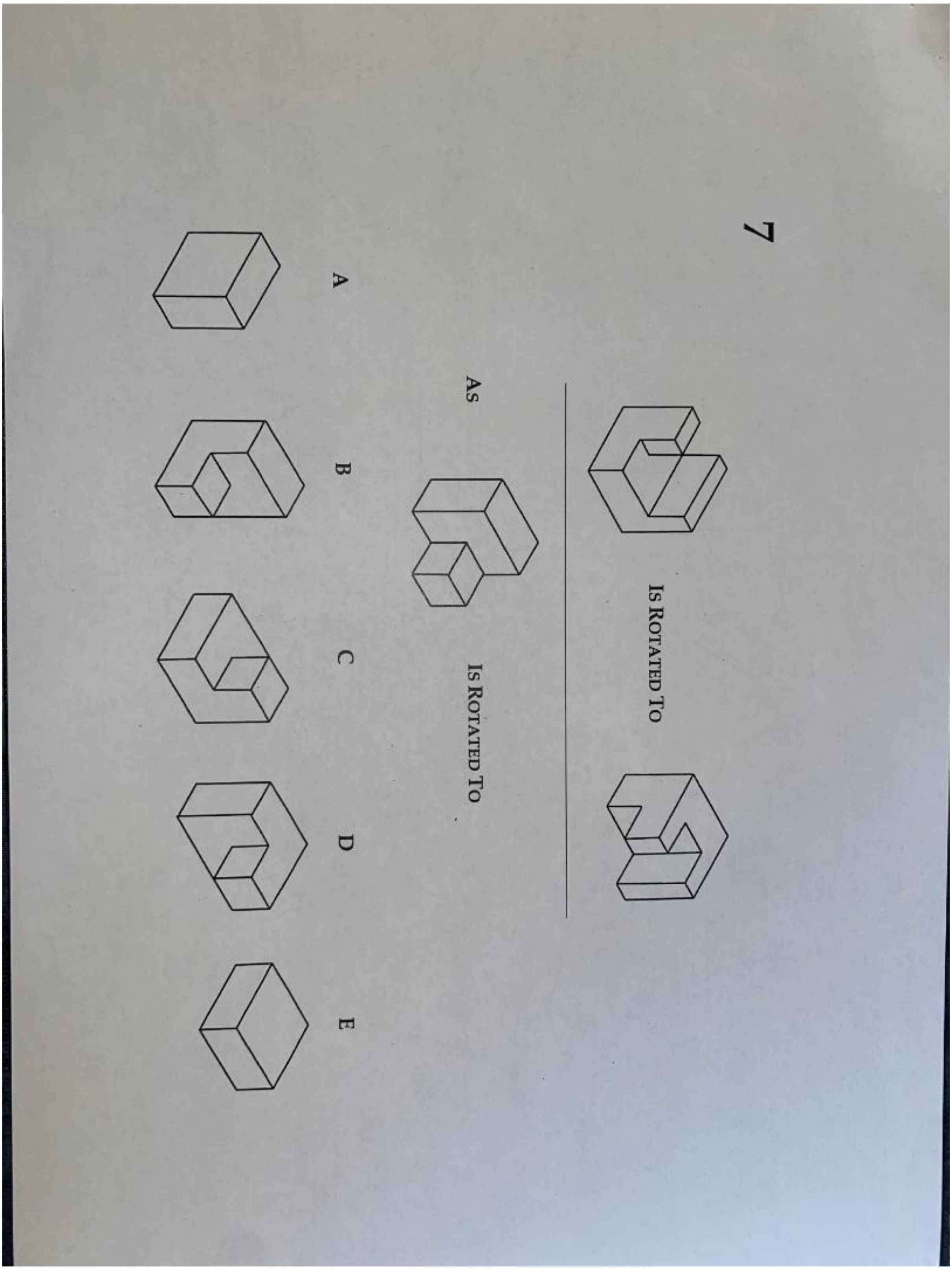
7
Is Rotated To
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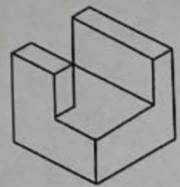
8



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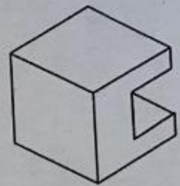

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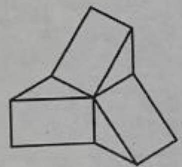

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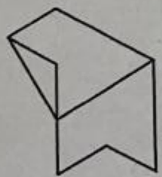

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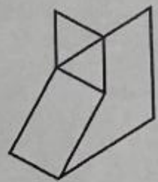

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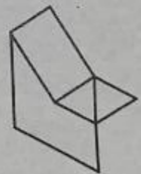

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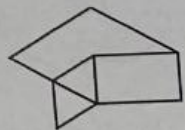

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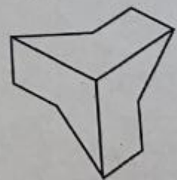

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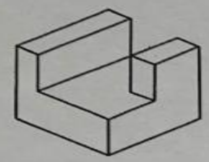

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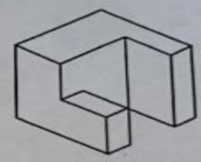

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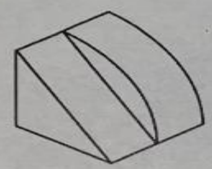

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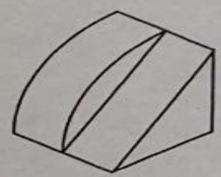

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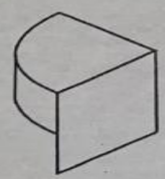

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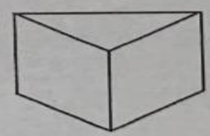

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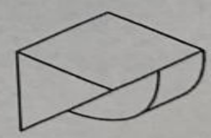

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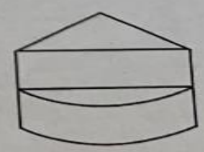

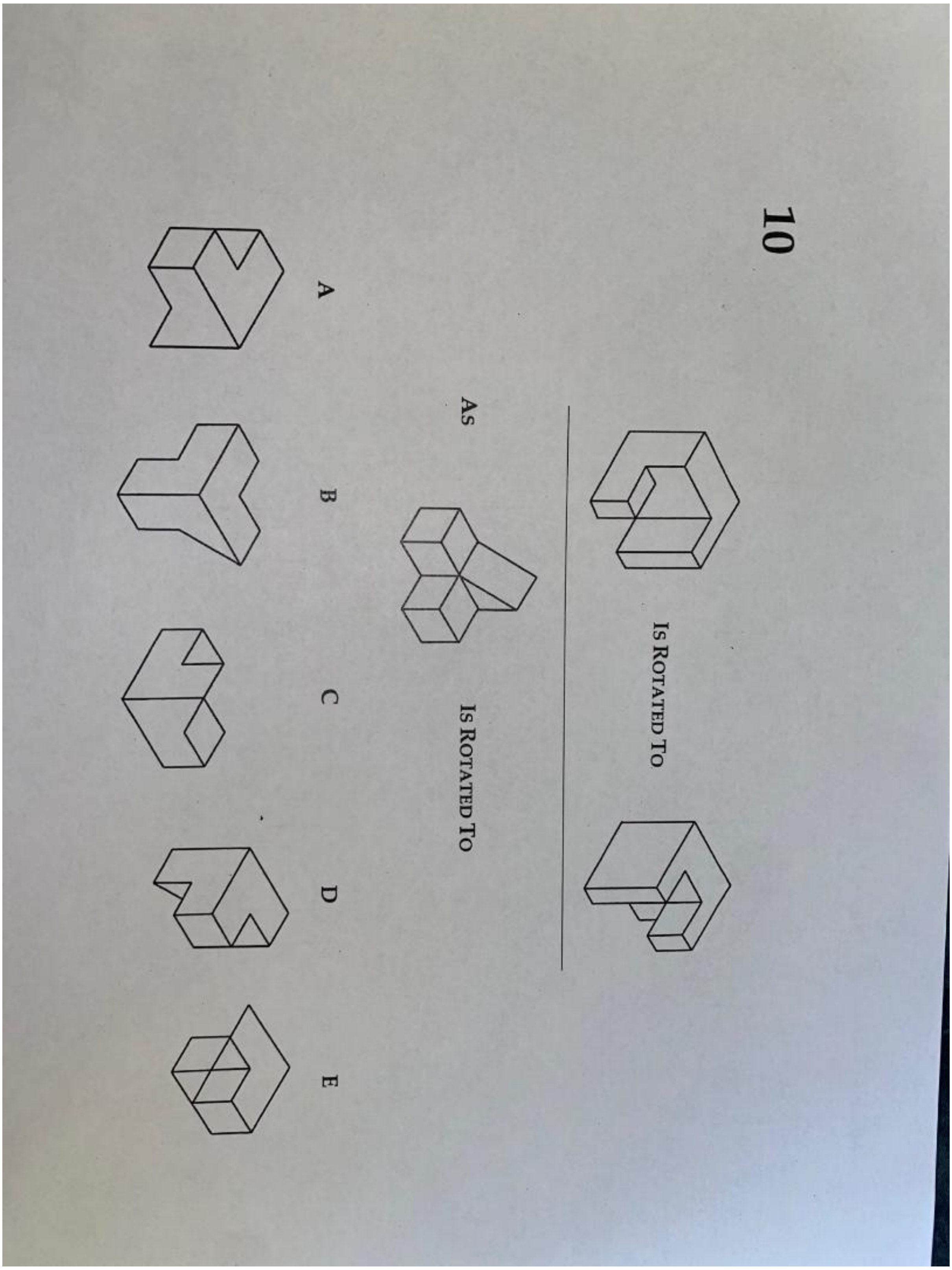
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THANK YOU VERY MUCH!

Appendix 3: Attitudes towards Physics (AP) Questionnaire

The Questionnaire below was used to survey AP of the participants who took part in my study.

STUDENT ATTITUDES TOWARD PHYSICS QUESTIONNAIRE

THE PURPOSE OF THE QUESTIONNAIRE IS TO FIND OUT ABOUT YOUR ATTITUDES TOWARD PHYSICS

ALL OF YOUR RESPONSES AND YOUR IDENTITY WILL BE KEPT STRICTLY CONFIDENTIAL AND NOT REVEALED TO ANYONE PLEASE ANSWER ALL QUESTIONS

In this questionnaire, there are no "correct" or "incorrect" answers. Your response to each question or statement should reflect what you truly believe. You must fill in the questionnaire using the pencil provided. If you make a mistake, simply erase the answer with the rubber provided. You can ask for help at any time if something is not clear to you, for example, if you are not sure how to answer a question. You will have 25 minutes to complete the questionnaire. If you finish early, please alert the person in charge by raising your hand. We would like to thank you for your cooperation.

Read each question or statement carefully before responding in one of the following ways: -

- Marking a Box with an [X] or [/] or [✓]
- Writing down a number
- Writing a sentence or short paragraph

SECTION 1: INFORMATION ABOUT YOU

1. What is your full name: _______________

2. Are you male or female: ________________

3. What is your age: ________________

4. What is your year group: ________________

5. What type of secondary co-educational establishment do you attend: -

   State school ☐

   Private school ☐

   Catholic school ☐

   Academy ☐

6. What is your target grade for GCSE physics: Place "X" in one box only: -

Grade A or	
Grade C or	
Grade D or	
Don't Know	

	Not at all	Less than once a month	Once or twice a month	Once a week	More than once a week
7. How often do you take part in the following physics activities?					
a) Physics clubs	☐	☐	☐	☐	☐
b) Physics master classes	☐	☐	☐	☐	☐
c) Physics competitions	☐	☐	☐	☐	☐
d) Physics related outings with your family	☐	☐	☐	☐	☐
e) Physics related outings with your school	☐	☐	☐	☐	☐

END OF SECTION 1

SECTION 2: YOUR FUTURE PLANS

	YES	NO
a) Are you going to continue with your studies after the age of 16?	☐	☐
	Go to b)	Go to c)

b) What subjects are you most likely to study after your GCSE's? Please write them down in order of preference:

1. __________________________because

2. __________________________because

3. __________________________because

4. __________________________because

c) I am NOT going to continue with my studies after the age of 16 because:

END OF SECTION 2

SECTION 3: STUDYING PHYSICS

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
a) I intend to continue to study physics after my GCSEs.	☐	☐	☐	☐	☐	☐
b) I think physics is a useful subject.	☐	☐	☐	☐	☐	☐
c) I think physics is an interesting subject.	☐	☐	☐	☐	☐	☐
d) I think physics will help me in the job I want to do in the future.	☐	☐	☐	☐	☐	☐
e) My friends are going to study physics after their GCSEs.	☐	☐	☐	☐	☐	☐
f) I am good at physics.	☐	☐	☐	☐	☐	☐
g) My teacher thinks that I should continue with physics beyond my GCSEs.	☐	☐	☐	☐	☐	☐
h) My friends think that I should continue with physics after my GCSEs.	☐	☐	☐	☐	☐	☐
i) I have been advised by someone else that physics is a good subject to study after my GCSEs.	☐	☐	☐	☐	☐	☐

END OF SECTION 3

SECTION 4: YOUR VIEWS ON PHYSICS

What you think science is about:

What you think physics is about:

Do you believe that society respects and values physics? Yes ☐ ☐ No

In the space below please give a reason for your choice:

SECTION 4: YOUR VIEWS ON PHYSICS (Continued)

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
a) People who are good at physics get well paid jobs.	☐	☐	☐	☐	☐	☐
b) Being good at physics impresses people.	☐	☐	☐	☐	☐	☐
c) Physics teaches you to think logically.	☐	☐	☐	☐	☐	☐
d) Physics helps you in solving everyday problems.	☐	☐	☐	☐	☐	☐
e) Physics improves your social skills.	☐	☐	☐	☐	☐	☐
f) To be good at physics, you need to be creative.	☐	☐	☐	☐	☐	☐
g) To be good at physics, you need to work hard.	☐	☐	☐	☐	☐	☐
h) Being good at physics makes you popular.	☐	☐	☐	☐	☐	☐
i) Physics is interesting.	☐	☐	☐	☐	☐	☐
j) Physics is important in making	☐	☐	☐	☐	☐	☐

new discoveries.

k) Those who are good at physics are clever.	☐	☐	☐	☐	☐	☐
l) These days, everybody needs to know some physics.	☐	☐	☐	☐	☐	☐
m) In physics, it is interesting to find out about the laws that explain different phenomena.	☐	☐	☐	☐	☐	☐
n) There is only one right way to solve any physics problem.	☐	☐	☐	☐	☐	☐

SECTION 4: YOUR VIEWS ON PHYSICS (Continued)

o) Do you enjoy doing physics homework? Respond by completing ONE of the sentences below

I enjoy doing physics homework because:

I don’t enjoy doing physics homework because:

p) Can you think of any experiences, such as a book you read, a film you saw, a place you visited or a person you met or know that may have changed the way you view physics? If yes, please explain.

END OF SECTION 4

SECTION 5: YOUR PHYSICS LESSONS

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
a) I look forward to physics classes.	☐	☐	☐	☐	☐	☐
b) In my physics lessons, my teacher explains how a physics idea can be applied to a number of different situations.	☐	☐	☐	☐	☐	☐
c) In my physics lessons, I have the opportunity to discuss my ideas about physics.	☐	☐	☐	☐	☐	☐
d) I do well in physics tests.	☐	☐	☐	☐	☐	☐
e) I enjoy my physics lessons.	☐	☐	☐	☐	☐	☐
f) I can see the relevance of physics lessons.	☐	☐	☐	☐	☐	☐
g) I find it difficult to apply most physics concepts to everyday problems.	☐	☐	☐	☐	☐	☐
h) When I am doing physics, I always know what I am doing.	☐	☐	☐	☐	☐	☐
i) When I am doing physics, I am	☐	☐	☐	☐	☐	☐

learning new skills.

j) When I am doing physics, I am bored.	☐	☐	☐	☐	☐	☐
k) When I am doing physics, I pay attention.	☐	☐	☐	☐	☐	☐
l) When I am doing physics, I get upset.	☐	☐	☐	☐	☐	☐
m) When I am doing physics, I daydream.	☐	☐	☐	☐	☐	☐
n) I like my physics teacher.	☐	☐	☐	☐	☐	☐

SECTION 5: YOUR PHYSICS LESSONS (continued)

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree
o) In my physics lessons, we are given the opportunity to do an investigation to test our own ideas.	☐	☐	☐	☐	☐	☐
p) I look forward to spending time in the laboratory doing practical investigations.	☐	☐	☐	☐	☐	☐
q) Thinking about your physics lessons, how do you feel you compare with the others in your group?	☐	☐	☐	☐	☐	☐

END OF SECTION 5

SECTION 6: YOUR PHYSICS TEACHER

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly
a) My physics teacher has high expectations of what the students can learn.	☐	☐	☐	☐	☐	☐
b) My physics teacher believes that all students can learn physics.	☐	☐	☐	☐	☐	☐
c) My physics teacher wants us to really understand physics.	☐	☐	☐	☐	☐	☐
d) My physics teacher sets us homework.	☐	☐	☐	☐	☐	☐
e) My physics teacher believes that mistakes are OK as long as we are learning.	☐	☐	☐	☐	☐	☐
f) My physics teacher is interested in me as a person.	☐	☐	☐	☐	☐	☐
g) My physics teacher seems to like all the students.	☐	☐	☐	☐	☐	☐
h) My physics teacher is interested in what the students think.	☐	☐	☐	☐	☐	☐
i) My physics teacher only cares about students who get good marks in physics.	☐	☐	☐	☐	☐	☐

j) My physics teacher lets us get away with not doing our homework.	☐	☐	☐	☐	☐	☐
k) My physics teacher treats all students the same regardless of their physics ability.	☐	☐	☐	☐	☐	☐
l) My physics teacher is good at explaining physics.	☐	☐	☐	☐	☐	☐
m) My physics teacher marks and returns homework quickly.	☐	☐	☐	☐	☐	☐

END OF SECTION 6

SECTION 7: HELP WITH PHYSICS

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	Cannot Say
a) I need help with physics.	☐	☐	☐	☐	☐	☐	☐
(b) I do extra physics at home (i.e. work not set by my teachers).	☐	☐	☐	☐	☐	☐	☐
(c) I think ICT is very useful in helping me to learn physics.	☐	☐	☐	☐	☐	☐	☐
(d) I use physics programmes on my computer to help me with my physics e.g. podcasts, BBC Bite Size, games etc.	☐	☐	☐	☐	☐	☐	☐
(e) I use online groups to help me learn physics.	☐	☐	☐	☐	☐	☐	☐
(f) Do any of these people ever help you with your physics work:							
i) Someone in my family	☐	☐	☐	☐	☐	☐	☐
ii) My friend(s)	☐	☐	☐	☐	☐	☐	☐
iii) A private tutor	☐	☐	☐	☐	☐	☐	☐
iv) Someone else not listed above	☐	☐	☐	☐	☐	☐	☐

END OF SECTION 7

SECTION 8: YOUR FAMILY'S VIEWS

	Strongly Agree	Agree	Slightly Agree	Slightly Disagree	Disagree	Strongly Disagree	Cannot Say
(a) Someone in my family i) Wants me to work hard and try to the best of my ability.	☐	☐	☐	☐	☐	☐	☐
ii) Wants me to be successful in the subjects in the subjects that I am interested in.	☐	☐	☐	☐	☐	☐	☐
iii) Wants me to do well in order to get a good job.	☐	☐	☐	☐	☐	☐	☐
iv) Wants me to be successful at school in physics.	☐	☐	☐	☐	☐	☐	☐
v) Wants me to be the best in my class in physics.	☐	☐	☐	☐	☐	☐	☐
vi) Wants me to talk to them about my physics work.	☐	☐	☐	☐	☐	☐	☐
vii) Thinks that you have to be born with physics talent to do well in physics.	☐	☐	☐	☐	☐	☐	☐
viii) Thinks that I should continue with physics after my GCSE's.	☐	☐	☐	☐	☐	☐	☐
ix) Thinks that anyone can do physics	☐	☐	☐	☐	☐	☐	☐

if they try hard enough.

(f) If my general standard of physics work slipped, my family would

i) Take away privileges or ground me	☐	☐	☐	☐	☐	☐	☐
ii) Threaten to punish me	☐	☐	☐	☐	☐	☐	☐

END OF QUESTIONNAIRE

Appendix 4: Focus Group Interview Schedule on AP

The topics discussed in the Focus Group Interviews are shown below.

1. How do you rate yourself in physics overall?
2. How do you rate your physics teacher in general?
3. How do you rate your physics lessons overall?
4. How do you rate your awareness of jobs, salaries and careers in physics?

Appendix 5: Extract of the National Curriculum for Science

List of Topics comprising the Physics Component of the National Curriculum for Science.

1. Energy

- energy changes in a system involving heating, doing work using forces, or doing work using an electric current: calculating the stored energies and energy changes involved
- power as the rate of transfer of energy
- conservation of energy in a closed system, dissipation
- calculating energy efficiency for any energy transfers
- renewable and non-renewable energy sources used on Earth, changes in how these are used.

2. Forces

- forces and fields: electrostatic, magnetic, gravity
- forces as vectors
- calculating work done as force x distance; elastic and inelastic stretching
- pressure in fluids acts in all directions: variation in Earth's atmosphere with height, with depth for liquids, up-thrust force (qualitative).

3. Forces and Motion

- speed of sound, estimating speeds and accelerations in everyday contexts
- interpreting quantitatively graphs of distance, time, and speed

- acceleration caused by forces; Newton's First Law
- weight and gravitational field strength
- decelerations and braking distances involved on roads, safety.

4. Waves in Matter

- amplitude, wavelength, frequency, relating velocity to frequency and wavelength
- transverse and longitudinal waves
- electromagnetic waves, velocity in vacuum; waves transferring energy; wavelengths and frequencies from radio to gamma-rays
- velocities differing between media: absorption, reflection, refraction effects
- production and detection, by electrical circuits, or by changes in atoms and nuclei
- uses in the radio, microwave, infra-red, visible, ultra-violet, X-ray and gamma ray regions, hazardous effects on bodily tissues.

5. Electricity

- measuring resistance using p.d. and current measurements
- exploring current, resistance and voltage relationships for different circuit elements; including their graphical representations
- quantity of charge flowing as the product of current and time

- drawing circuit diagrams; exploring equivalent resistance for resistors in series
- the domestic a.c. supply; live, neutral and earth mains wires, safety measures
- power transfer related to p.d. and current, or current and resistance.

6. Magnetism and Electromagnetism

- exploring the magnetic fields of permanent and induced magnets, and the Earth's magnetic field, using a compass
- magnetic effects of currents, how solenoids enhance the effect
- how transformers are used in the national grid and the reasons for their use.

7. Particle Model of Matter

- relating models of arrangements and motions of the molecules in solid, liquid and gas phases to their densities
- melting, evaporation, and sublimation as reversible changes
- calculating energy changes involved on heating, using specific heat capacity; and those involved in changes of state, using specific latent heat
- links between pressure and temperature of a gas at constant volume, related to the motion of its particles (qualitative).

8. Atomic Structure

- the nuclear model and its development in the light of changing evidence
- masses and sizes of nuclei, atoms and small molecules
- differences in numbers of protons, and neutrons related to masses and identities of nuclei, isotope characteristics and equations to represent changes
- ionization: absorption or emission of radiation related to changes in electron orbits
- radioactive nuclei: emission of alpha or beta particles, neutrons, or gamma rays, related to changes in the nuclear mass and/or charge
- radioactive materials, half-life, irradiation, contamination and their associated hazardous effects, waste disposal
- nuclear fission, nuclear fusion and our Sun's energy

9. Space Physics

- the main features of the solar system.

(Physics Curriculum: Extract from DfE, 2015:14-17)